INDIANAPOLIS CSO

FALL CREEK / WHITE RIVER TUNNEL

PHASE 1B GEOTECHNICAL INVESTIGATION

FINAL WORK PLAN

May 14, 2007

BLACK & VEATCH
Corporation

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1. INTRODUCTION

1.1 PURPOSE

This work plan outlines the Indianapolis Combined Sewer Overflow (CSO) – Fall Creek/White River Tunnel Phase 1B Geotechnical Investigation and contains project-specific standard methods to collect the geologic and geotechnical information necessary to complete the investigation. This geotechnical investigation and subsurface drilling program will provide information required for preliminary design, detailed design, and construction phases and operating requirements of the project. Technical specifications for the subsurface drilling and testing program for the geotechnical investigation are presented in Appendix B - Drilling Consultant Scope of Work with Black & Veatch.

This work plan identifies the following:

- Number and location of boreholes to be drilled
- Number and location of piezometers to be installed
- Field testing procedures
- Reporting requirements
- Laboratory testing and data reporting requirements
- Health & safety procedures
- Storage location and transportation needs for core samples
- Field and office support needed for investigation
- Permits required for investigation
- Schedule of boring program
- Samples of field forms to be used

Included is an explanation and description of the geotechnical investigation methods and standard practices to be used in this investigation. Also provided is the standard format for documenting information in the field.

1. INTRODUCTION

Field investigations are exploratory in nature and should remain flexible to accommodate specific site conditions and utilization. All field personnel should make careful observation of the actual conditions encountered and unexpected occurrences, and be prepared to modify the fieldwork as needed in order to obtain the desired information.

This plan is to provide a field reference for employees supervising field investigations and responsible for providing descriptions of subsurface materials and site conditions encountered.

1.2 PROJECT SCHEDULE

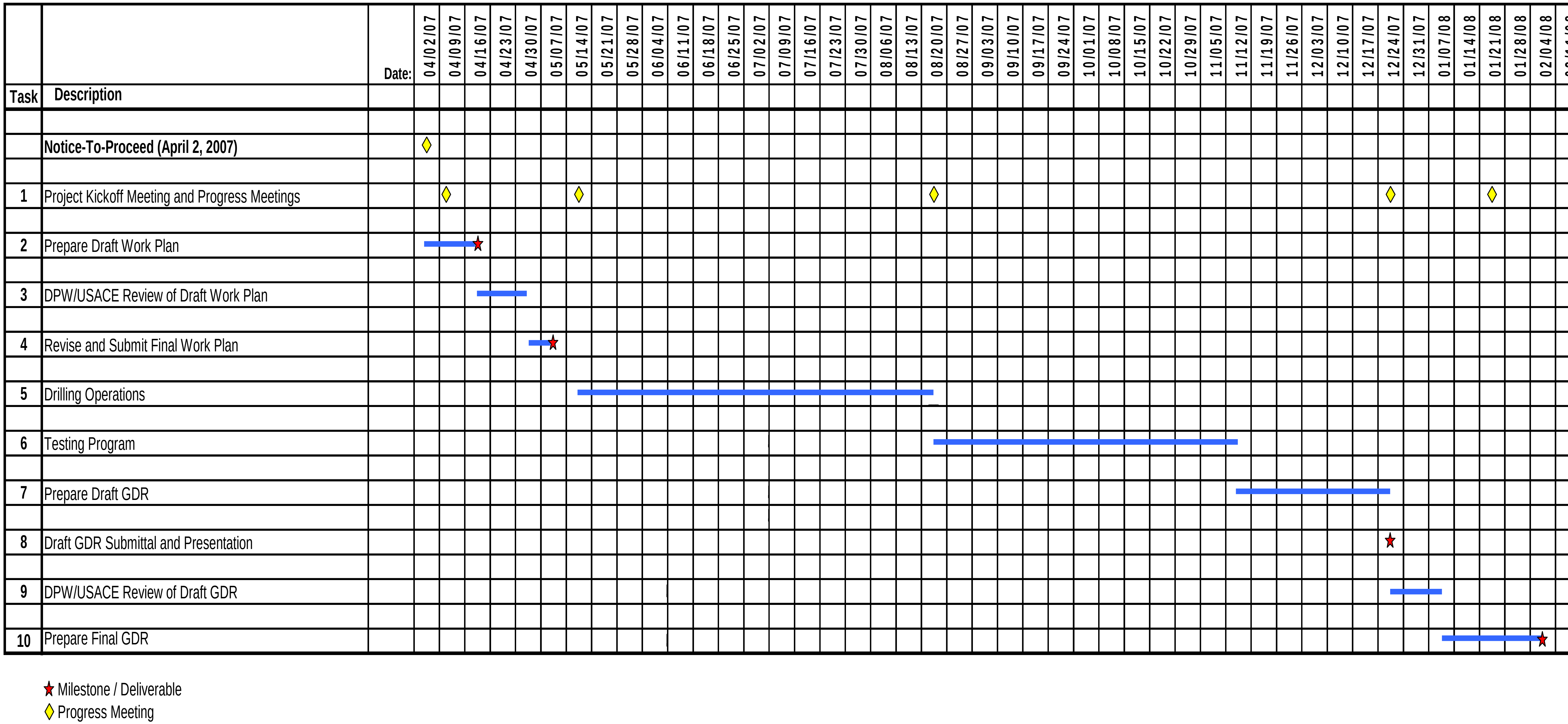
The project schedule is included as Figure 1.1, and the timeline follows the prime contract schedule with Indianapolis DPW.

1.3 PHASE 1A AND PHASE 1B GEOTECHNICAL INVESTIGATION

The Phase 1A and Phase 1B Geotechnical Investigations are being completed along the preliminary Fall Creek/White River tunnel alignment in Indianapolis, Indiana. The evaluation includes borings collected along the tunnel alignment from Bluff Road working shaft on the south end to the Sutherland Avenue retrieval shaft on the north end and many of the intermediate drop shafts. The boring locations completed for Phase 1A, and the approximate boring locations to be completed for Phase 1B are identified on Figure 1-2. A summary of the completed Phase 1A boring locations are also indicated in Table 1-1.

1. INTRODUCTION

Figure 1-1
Fall Creek/White River Tunnel Project
Phase 1B Geotechnical Investigation Schedule



1. INTRODUCTION

INSERT FIGURE 1-2

1. INTRODUCTION

Table 1-1
Phase 1A Boring Summary

BORING	APPROXIMATE LOCATION	PARCEL ID	OWNERSHIP
B-1	2912 BLUFF ROAD	1089790	PRIVATE
B-3	1720 S. WEST STREET	1102623	PUBLIC
B-5	201 SOUTH WHITE RIVER PKWY WDR	N/A	PUBLIC
B-6	1027 OWOSSO STREET	1066858	PUBLIC
B-10	1500 WATERWAY BOULEVARD	1081217	PUBLIC
B-13	2069 MONTCALM STREET	1047803	PUBLIC
B-15	320 FALL CREEK BOULEVARD	N/A	PUBLIC
B-17	2954 GUILFORD AVENUE	1083044	PUBLIC
B-20	3500 SUTHERLAND AVENUE	1100676	PUBLIC

* Right of Entry access granted by Owner

2. PROJECT DESCRIPTION AND CONTACTS

2.1 PROJECT DESCRIPTION

To obtain geotechnical and hydrogeological data for use during the planning and design of the tunnel system, a Phase 1 geotechnical investigation program was recommended in the 2005 Fall Creek Evaluation Study Report. To accommodate funding constraints the Phase 1 program was divided into two separate investigations; the Phase 1A geotechnical program that was completed in March 2006 and the Phase 1B geotechnical program that this work plan addresses. As part of the Phase 1B program, Black & Veatch will execute field and laboratory investigations and perform the test borings and in-situ testing required to further characterize the subsurface soil, rock and groundwater conditions.

The goals of the Phase 1B Geotechnical Program are as follows:

- Further identify the geologic units, solution features, faulting, joint characteristics, etc. and their extent along the tunnel alignment.
- Further identify top of rock and depth of weathering along the tunnel alignment.
- Characterize the rock mass of each geologic unit including strength, hardness, abrasiveness, slake propensity, geologic structure and all other geologic, geotechnical and engineering factors that may control borability and constructability.
- Characterize the contacts between geologic units.
- Characterize the hydrogeology along the tunnel alignment.
- Determine the corrosivity of the soil and groundwater.
- Screen for environmental contamination along the tunnel alignment and at selected proposed shaft sites.
- Prepare a Phase 1B Geotechnical Data Report to document preliminary design conditions for the deep bedrock tunnel. This report will provide data and discuss the results of both Phases 1A and 1B.

2. PROJECT DESCRIPTION AND CONTACTS

The Phase 1B geotechnical investigation includes drilling 12 vertical and five inclined borings; soil and rock sampling and testing; installation of 12 piezometers; packer testing the boreholes; downhole video-logging of up to eight deep boreholes; monitoring for hazardous and explosive gases at the drill collar; collection of environmental samples for testing if contamination is encountered; and collecting 26 rounds (biweekly for one year) of groundwater measurements from the existing piezometers. With the exception of the long-term groundwater monitoring, the field program is scheduled to be completed in 10 months. The attached figure presents the locations of the proposed boreholes.

Specifically, the following activities will be completed by Black & Veatch:

- Oversee the drilling activities with a full-time registered geologist or geotechnical engineer. The borings to be completed for the program are summarized in Table 2-1.
- Obtain drilling and well installation permits and logs required for the work. Boring investigations shall comply with applicable state and local laws in effect at the time of execution of the work and accepted standards of practice for geotechnical investigations.
- Provide a drawing or sketch and a completed permit application for each private property site for DPW to secure right-of-entry to complete the geotechnical borings. Permission to enter upon the sites will be secured by DPW prior to the start of any activities at each boring location.
- Use a gas meter and photoionization detector (PID) to monitor the subsurface at the top of the boreholes for hazardous gases and volatile organic compounds during drilling. The gas meter shall monitor for hydrogen sulfide and methane.
- Collect and analyze soil samples for potential contamination. Up to 24 samples (two per vertical boring) shall be collected and analyzed. If contaminated material is encountered, work may be temporarily suspended and DPW will be immediately notified.

2. PROJECT DESCRIPTION AND CONTACTS

Table 2-1
Phase 1B Boring Schedule

Boring	Location	Depth	Orientation	Media Sampled
B-1B	Bluff Road Shaft	50 ft	Vertical	NA [1]
B-2	DS-01	270 ft	Inclined 20° from Vertical Oriented N10°W	Rock
B-4	DS-03	270 ft	Vertical	Soil & Rock
B-7	DS-05	260 ft	Vertical	Soil & Rock
B-8	DS-06	260 ft	Vertical	Soil & Rock
B-9	DS-07	260 ft	Inclined 20° from Vertical Oriented N10°W	Soil & Rock
B-10B	DS-08	50 ft	Vertical	NA [1]
B-11	DS-09	260 ft	Vertical	Soil & Rock
B-12	DS-10	260 ft	Inclined 20° from Vertical Oriented N10°W	Soil & Rock
B-14	DS-11	260 ft	Vertical	Soil & Rock
B-16	DS-13	260 ft	Inclined 20° from Vertical Oriented N10°W	Soil & Rock
B-18	DS-15	260 ft	Vertical	Soil & Rock
B-19	DS-16	250 ft	Inclined 20° from Vertical Oriented N10°W	Soil & Rock
B-20	Sutherland Ave Shaft	250 ft	Vertical	Soil & Rock
B-21	DS-19	~100 ft (top of rock)	Vertical	Soil
B-22	DS-20	~100 ft (top of rock)	Vertical	Soil
B-23	DS-21	250 ft	Vertical	Soil & Rock

[1] Borings shall be drilled with no soil samples collected (i.e., drilled blind)

2. PROJECT DESCRIPTION AND CONTACTS

- Perform field testing and classifications as recommended in this work plan. A qualified geologist or geotechnical engineer shall review and classify soil and rock samples in the field throughout the project period.
- Coordinate and complete surveying for each Phase 1B boring location including the ground surface and top of casing elevations.
- Install 2-inch nominal diameter PVC piezometers in all vertical holes. The screen lengths will be 30 feet long.
- Backfill and grout completed test borings. Within one week of completing all test borings that do not have piezometers, backfill all borings using cement-bentonite grout and original soil cuttings in accordance with the requirements of the Indiana Department of Environmental Management (IDEM). Any remaining spoils from the exploration program shall be distributed evenly across the site or collected and disposed off-site by the drilling contractor assuming that the soil is not contaminated.
- Analytical testing of groundwater shall be conducted on representative samples retrieved from the boreholes. Samples shall be collected and tested from the developed piezometers for the potential to cause corrosion of metals. In addition, up to 24 samples (two samples per vertical boring) shall be collected and analyzed for volatile and semivolatile organic compounds.
- Conduct a field and laboratory testing program to evaluate the pertinent physical and engineering properties of the subsurface soil and rock. Anticipated laboratory tests are included in the field and laboratory tests listed in Table 2-2.
- Conduct permeability testing of the rock mass using bottom up techniques and inflatable packers.
- Downhole video logging will be conducted on up to eight borings to view the in-situ orientation and characteristics of fractures, bedding planes, joints, and solution features. Video logging will generally be conducted on the borings that exhibited the highest conductivity as determined by water pressure testing.

2. PROJECT DESCRIPTION AND CONTACTS

Table 2-2
Phase 1B Sampling and Testing Schedule

Test/Sampling Method	Reference	Estimated Quantity [1]
Standard Penetration test	ASTM D1586	Every 5 feet in soil
Thin-Walled Tube	ASTM D1587	24 samples [2]
Grain Size Analysis	ASTM D4223	30 samples
Atterberg Limits	ASTM D4318	12 samples [2]
Consolidation	ASTM D2435	12 samples [2]
Rock Coring	---	Entire length of boring in rock
Water Pressure Packer Testing	---	Entire length of boring in rock
Moisture Content (Soil)	ASTM D2216	24 samples
Chemical Analysis of Soil (sulfates and chlorides)	[4]	24 samples
Environmental Analysis (VOCs and SVOCs)	[4]	24 samples
Unconfined Compressive Strength (Soil)	ASTM D2166	6 samples
Unconfined Compressive Strength (Rock)	ASTM D2938	36 samples
Rock Moduli in Uniaxial Comp.	ASTM D3148	9 samples
Indirect Tensile (Brazilian) Strength	ASTM D3967	18 samples
Cerchar Abrasivity	[5]	9 samples
Bulk Density	[6]	18 samples
Moisture Content (Rock)	ASTM D2216	18 samples
Slake Durability	ASTM D4544	9 samples
Punch-Penetration	[5]	9 samples
Direct Shear (Rock)	ASTM D5607	9 samples
Thin Section Analysis	[7]	9 samples
Hydrometer Analysis	---	6 samples

1 Samples will be collected from vertical holes, not inclined holes with the exception of rock core and water pressure tests which will be conducted on vertical and inclined borings.
2 Required only in cohesive soils, if encountered.
3 Sample preparation by wet method of ASTM D2217, Procedure B.
4 Samples collected from soil and groundwater. Environmental samples only required if readings detected by field meter (i.e., PID) for volatile compounds.
5 As performed by the Colorado School of Mines and Excavation Engineering and Earth Mechanics Institute or equivalent.
6 As described in Suggested Methods for Rock Characterization, Testing, and Monitoring (1981). International Society for Rock Mechanics Commission on Testing Methods, E.T. Brown, editor.
7 As described in “Suggested Methods for Petrographic Description of Rocks”, International Society for Rock Mechanics, 1977.

2. PROJECT DESCRIPTION AND CONTACTS

Upon completion of the Phase 1B Geotechnical Program, a Draft and Final Geotechnical Data Report (GDR) shall be prepared to provide data and discuss the results of both Phases 1A and 1B subsurface investigation programs. Test boring logs and results from field and laboratory tests will be provided in the Appendices. The GDR will include the following:

- Description of exploration programs
- Description of regional and site geology and hydrogeology
- Testing results and piezometric data
- Boring and well construction logs
- Identification of data gaps
- Recommendations for the Phase 2 geotechnical exploration program

2.2 PROJECT PERMITS

Project boring and piezometer installation permits shall be obtained by TesTech, Inc. prior to the start of drilling services. Black & Veatch shall work with Indianapolis DPW to obtain applicable permits or notices to access all sites prior to the start of field efforts.

2.3 PROJECT CONTACTS

FIELD INVESTIGATION TEAM

John Trypus, Engineering Manager	cell:	(317) 965-2223
Black & Veatch	office:	(317) 570-8331
Norm Holst, Geotechnical Engineer	cell:	(816) 304-0040
Black & Veatch	office:	(913) 458-3125
Cary Hirner, Sr. Geotechnical Engineer	cell:	(913) 549-0966
Black & Veatch	office:	(913) 458-6653

2. PROJECT DESCRIPTION AND CONTACTS

Philip Ward, Geologist	cell:	(317) 439-8047
QEPI	office:	(317) 351-4255
James McKelvey, Technical Reviewer	cell:	(843) 364-1524
Black & Veatch	office:	(843) 266-0667

INDIANAPOLIS DEPARTMENT OF PUBLIC WORKS (DPW)
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Indianapolis, IN 46201
Mr. John Oakley
Tel: (317) 327-8441
Fax: (317)327-8432
Email: joakley@indygov.org

INDIANAPOLIS CLEAN STREAM TEAM (CST)
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Indianapolis, IN 46204
Mr. David Klunzinger
Tel: (317) 327-8720
Fax: (317) 327-8599
Email: dklunzin@indygov.org

BLACK & VEATCH
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Fax: (317) 570-8356
E-mail: Trypusjf@bv.com

2. PROJECT DESCRIPTION AND CONTACTS

Quality Environmental Professionals, Inc. (Geotechnical Field Support)
1611 South Franklin Road
Indianapolis, IN 46239
Contact: Mr. Philip Ward, LPG
Tel: (317) 351-4255
Fax: (317)351-4265
Email: pward@qepi.com

TesTech, Inc. (Geotechnical Exploration Services, Drilling Subcontractor)
8534 Yankee Street
Dayton, OH 45458
Contact: Mr. Larry King, P.E., P.S.
Tel: (937) 435-3200
Fax: (937) 291-6549
Email: king@testechinc.com

3. EXPLORATION METHODS

The general objective of this exploration program is to identify the significant features of the geologic environment which may impact the proposed design, construction and operation of the tunnel system. The primary focus of this section is to ensure consistent documentation of the methods that shall be used for this specific site investigation. This section focuses on the sampling of geologic materials utilizing soil borings and core borings.

The following aspects of the field exploration program should be reviewed and understood by the project team:

- Goals of the geotechnical investigation
- Project schedule
- Client contacts
- Sampling procedures
- Sampling requirements
- Criteria for the final depth of drilling
- Site access
- Surveying requirements
- Utility clearance
- Permits
- Security
- Health and Safety
- Disposal of cuttings and drilling fluid
- Site restoration
- Methods to locate borings
- Well installation procedures
- Closure of borings
- Traffic
- Standards to be implemented

3. EXPLORATION METHODS

The drilling Contractor is responsible for a hazardous environmental condition created with any materials brought to the site by the drilling Contractor, Subcontractors, Suppliers, or any other parties for which the Contractor is responsible.

If the drilling Contractor or associated subcontractors encounters a hazardous environmental condition or creates a hazardous environmental condition, the drilling Contractor shall immediately do the following:

- Secure or otherwise isolate the condition.
- Stop work in connection with the condition and in any area affected thereby.
- Notify the Owner (Indianapolis Department of Public Works) and Engineer (Black & Veatch) and promptly thereafter confirm such notice in writing.

4. DRILLING AND SAMPLING METHODS

4.1 SOILS

Soil will be investigated through the use of a hollow stem auger or rotary washed boring.

4.1.1 Soil Sampling

The typical soil samplers include the Standard Penetration Test sampler and thin-walled tube sampler. These methods are the most commonly used for obtaining soil samples in subsurface investigations. The following is a brief explanation of these methods:

- Standard Penetration Test (SPT): SPT samplers are used to obtain representative samples suitable for field examination of soil texture and fabric and for laboratory tests, including measurement of grain size distribution, moisture content and Atterberg limits. Samplers for this project shall be 1.5-inch-diameter, 18-inch-long standard samplers per ASTM D 1586. SPT samplers shall be driven into the soil with an automatic hammer falling on the drill rods in accordance with ASTM D 1586. Each sampler shall be driven 18 inches or to refusal. The field geologist shall record the number of blows required to drive the sampler for each 6 inches of penetration.
- Thin-Walled (TW) Tube Sampler: TW tube samplers are used to obtain relatively undisturbed samples of cohesive soils for laboratory testing of strength and compressibility. TW tubes are normally pressed into the soil by hydraulically applied force. The rods and sampler are rotated clockwise about two revolutions to free the sampler by shearing the soil at the sampler bottom. The sample is withdrawn slowly from the hole with an even pull. Samplers for this project shall be standard as per ASTM D 1587.

4. DRILLING AND SAMPLING METHODS

4.2 ROCK

Coring will be used in obtaining samples from rock. This is accomplished with a rotary drill rig and a core barrel.

4.2.1 Rock Sampling

Rock is normally sampled with rock core barrels. This method is used for obtaining rock samples in subsurface investigations. The following briefly highlights items important to the rock coring procedure:

- Rock coring is used to obtain intact core samples with a high percentage of core recovery. Water will be used in drilling to remove cuttings. Allowable types of core barrels will be as specified in the driller's Contract. Core barrel length will be limited to ten feet, though for practical purposes, core run length will generally be limited to a maximum of five feet.
- The following information pertaining to drilling characteristics shall be recorded in the remarks section of the boring log:
  - Changes in penetration rate or drilling speed in minutes or seconds per foot
  - Dropping of drill rods
  - Changes in drill operations by driller (down pressure, rotation speed, etc.)
  - Changes in drill bit condition
  - Unusual drilling action (chatter, bouncing, binding, etc.)
  - Loss of drilling fluids, color changes, or change in drilling pressure
- The rock cores shall be handled carefully from barrel to box to preserve mating across fractures and fracture-filled materials. Breaks in core that occur during or after the core is transferred to the core box should be fitted and marked with three short parallel lines across the fracture trace to indicate a man-made break.

5. EXPLANATION OF FIELD LOG FORMS AND SAMPLE COLLECTION

This section provides an explanation of the forms used in the field for recording data from this site investigation. These field forms and completed field logs are included at the end of this work plan in Appendix A for further reference. Procedures for the collection and labeling of soil samples and rock core are also included.

5.1 BORING LOG FORM

The following is a list of information to be recorded on the boring log form. The number of each item of information on the list has a corresponding number shown on the example boring log form presented in Appendix A of this document. The number on the log form indicates the space or the column where the information is to be recorded:

1. Client*
2. Name of the project*
3. Project number*
4. Boring number*
5. Sheet number*
6. County, city and state where the project is located.**
7. If available, coordinates of boring at the time of drilling according to site grid system (temporary or permanent) or State Plane coordinates. Indicate offset location of boring from staked location above surveyed coordinates.**
8. If available, ground elevation of boring as surveyed, datum (i.e., MSL or plant), and orientation of borehole**
9. Total depth of boring at completion of drilling in feet and tenths of a foot**
10. Topographic, vegetative, and other surface conditions at or near the boring (steepness and direction of slope, whether the boring is on a county road, in a parking lot, rock outcrop nearby, etc.) and orientation of drill hole if not vertical**
11. Date boring started**
12. Date boring completed**

5. EXPLANATION OF FIELD LOG FORMS AND SAMPLE COLLECTION

13. Drilling contractor firm's name**
14. Type and model of drill rig**
15. Name of driller and field geologist**
16. Name of field representative monitoring the drilling rig; initial of given name and full surname. Date log sheet was begun.*
17. Name of individual who checks samples and core in field or edits log in office; initial of given name and full surname. Date log was checked.*
18. Name of individual who approves final boring log; initial of given name and full surname. Date log was approved.*

<u>Legend</u>
*record on all pages
**record on first page only

SAMPLING

19A. Sample type: Standard Penetration Test (SPT) or thin wall (TW).
20A. Sample number: consecutive number of all samples regardless of type. SPT sample attempts with no recovery receive a number; TW sample attempts without recovery do not receive a number but will be shown.
21A. Set: the number of blows in the SPT to drive the SPT sampler the first 6 inches or fraction thereof.
22A. 2nd: the number of blows in the SPT to drive the SPT sampler the second 6 inches or fraction thereof.
23A. 3rd: the number of blows in the SPT to drive the SPT sampler the final 6 inches or fraction thereof.
24A. N value: the sum of the blows required for the second and third 6-inch increments of the penetration. If the sampler is not driven the full 18 inches, the blows shall be recorded in the proper columns indicating the fraction of the last 6-inch increment to be penetrated. Refusal shall be defined as a 6-inch

5. EXPLANATION OF FIELD LOG FORMS AND SAMPLE COLLECTION

increment that requires more than 50 blows to penetrate. The N value shall be indicated in column as 50 + when refusal is reached.

25A. Sample Recovery: SPT - total length of the sample recovered in feet and tenths of foot from three 6-inch penetration increments or fraction thereof. Slough material shall not be included in this measurement, and not saved in the sample container. The recovery shall be measured in depth as from the top of the drive. TW - total length of the sample recovered in feet and tenths of a foot from the thin wall tube. Slough material shall not be included in this measurement, and shall be removed prior to sealing the tube for transport.

CORING

19B. Core size: record the standard designation for the coring equipment used; e.g. NX, HQ, etc.

20B. Run number: runs with no core recovered still receive a number.

21B. Run length: the distance (measured in feet and tenths of a foot) the boring advanced during each run. At the depth corresponding to the beginning and end of each core run, draw a line across columns 19 through 25 and write the appropriate depth above this line.

22B. Run recovery: the length of rock core recovered in feet and tenths of a foot for each core run.

23B. Rock quality designation (RQD) recovery: the total (sum) length in feet and tenths of a foot of all pieces of sound core four inches or longer in length. The length of core pieces measured along the center line of the core. Breaks in core caused by drilling or handling are disregarded. A detailed discussion of RQD is found in Section 6.2.

24B. Percent recovery: the length of core recovered divided by the length of core run, expressed as percent.

25B. RQD: RQD recovery divided by the length of the core run, expressed as a percent. Calculate this for each rock type in each run.

5. EXPLANATION OF FIELD LOG FORMS AND SAMPLE COLLECTION

26. Write in the proper number for the depths at ten foot intervals and depths of changes in materials that do not fall on half-foot increments.
27. Indicate graphically the type, depth, and length of the sample attempts.
28. Indicate changes in materials using a solid line when the change is visible in the sample or rock core, or a dashed line when the change is gradual or inferred.
29. Classification of Material; provide a classification and description of material sampled and in the format as presented in Section 5 of this manual.
30. Remarks: information in this column should pertain to the drilling method used, drill bit type and size, type of drilling fluid, sampling procedures (such as use of automatic hammer, non-standard samplers, etc.), open hole testing performed and depth of interval, drilling fluid return, hard or fast drilling, hazardous and explosive gas readings, temporary casing installed, borehole stability (i.e., caving), voids, pocket penetrometer and torvane values, and unusual occurrences or changes during drilling (i.e., drilling tools lost in borehole, odors, pollutants, unexpected utilities, replaced drill bit, driller changed down pressure, etc.).
    a. After drilling is completed, a solid line shall be drawn across the Log, Classification and Remarks columns at the depth the boring was terminated. Beneath this line in the Remarks column the following shall be written:
       "Bottom of boring at [depth of borehole in feet and tenths of a foot]."
    b. If the water level in the boring was not measured, beneath the "bottom of the boring" statement shall be written:
       "Water level not recorded."
    c. If the water level was recorded the statement should say:
       "Water level at [depth to water in feet and tenths of a foot] at completion of drilling (or time since drilling was completed)."

5. EXPLANATION OF FIELD LOG FORMS AND SAMPLE COLLECTION

d. If the boring remains open and subsequent water level readings are made, the last measurement shall be recorded as:
   "Water level at [depth to water in feet and tenths of a foot) on (date of measurement]."
e. If a piezometer or monitoring well is installed in the boring it shall be recorded as:
   "[Piezometer or Monitoring well] installed on [date of installation]."
f. If the boring is abandoned it shall be recorded as:
   "Boring was backfilled with [material type] and [placement procedure]."

In the interest of brevity and uniformity when filling out the Field Boring Log, the following abbreviations may be used on the form:

w/	-	with
<	-	less than
>	-	greater than
&	-	and
a/a	-	as above
~	-	approximately
@	-	at

No other abbreviations are authorized to limit confusion during editing. The field log should resemble the final log as closely as possible. It is a good practice to document everything that occurs in the field related to the drilling on the field log. This should not include comments about the driller's capability, your supervisor, or the client.

5. EXPLANATION OF FIELD LOG FORMS AND SAMPLE COLLECTION

5.2 PIEZOMETER/MONITORING WELL INSTALLATION LOG FORM

The following is a list of information to be recorded on the piezometer/monitoring well installation log form. The number of each item of information on the list has a corresponding number shown on the example installation log form presented in this document. The number on the log form indicates the space or column where the information is to be recorded:

1. Client
2. Name of the project
3. Project number
4. Piezometer/monitoring well number should correspond to the boring number if in or near an existing boring.
5. County, city and state where the project is located.
6. Coordinates of the piezometer/monitoring well at the time of the installation according to the site grid system (temporary or permanent) or State Plane Coordinates. Indicate offset location of well from staked location above the surveyed coordinates.
7. Ground elevation of the piezometer/monitoring well as surveyed and datum (i.e., MSL or plant).
8. Date the piezometer/monitoring well was installed, or completed if not installed in one day.
9. Soil or bedrock strata monitored (all units in contact with the screen and/or filter pack).
10. Name of field representative, initial of given name and full surname.
11. Name of the individual who checks or edits installation log; initial of given name and full surname.
12. Name of the individual who approves the final installation log; initial of given name and full surname.
13. Name of the drilling contractor firm
14. Type and model number of the drill rig

5. EXPLANATION OF FIELD LOG FORMS AND SAMPLE COLLECTION

15. Name of the driller and field geologist
16. Height in feet and tenths of a foot from the ground surface to the top of the uncapped riser pipe.
17. Depth from ground surface to the bottom of the filter pack in feet and tenths of a foot.
18. Depth from ground surface to the bottom of the well screen in feet and tenths of a foot.
19. Depth from the ground surface to the bottom of the upper seal (or top of filter pack) in feet and tenths of a foot.
20. Vertical height of the upper seal in feet and tenths of a foot.
21. Length of screen installed in feet and tenths of a foot.
22. Vertical height of the bottom seal in feet and tenths of a foot. Enter 0.0 foot if well is set to bottom of boring.
23. Type of surface seal; such as compacted earth, sand-cement grout, cement-bentonite grout, etc.
24. Outside diameter of riser and type of riser installed; such as 2 inch O.D. PVC, 6 inch O.D. steel, etc.
25. Type of material and form used for the seal; such as 1/8 inch bentonite pellets, bentonite chips, bentonite slurry, etc.
26. Type of screen and size of openings installed; such as 2 inch O. D. PVC with 0.01 inch slots, 4 inch O.D. steel with 1/8 inch drilled holes, etc.
27. Type and gradation of filter pack material; such as 10-20 silica sand, pea gravel, etc.
28. Type of bottom seal material; grout, bentonite, drill cuttings, etc. If piezometer/ monitoring well is set to bottom of boring enter N/A.
29. Diameter of the borehole in inches.
30. Describe the drilling of the boring and the installation procedures used to construct the well.
31. Describe how the well was developed and include details of the construction and materials used in installing protective casing, lockable caps, concrete pads, weep holes, and guard posts.

6. DESCRIPTION AND CLASSIFICATION OF MATERIALS

This section provides a guide for the description and classification of soil and rock samples in the field.

6.1 DESCRIPTION OF SOILS

Soils shall be described in accordance with ASTM D 2488, Visual-Manual Procedure. A copy of this standard is included in Appendix C along with ASTM D 2487, Unified Soil Classification Procedure. Visual examination and simple manual tests give standardized criteria and procedures for describing and identifying soil. The physical characteristics of the soil such as angularity, shape, color, odor, moisture condition, cement type, consistency, degree of cementation, structure, particle size, dilatancy, toughness, plasticity, and organic content are described to aid in classifying the soil. This practice provides qualitative information only.

When describing soils in the field use the most conservative description based on the intended design. If it is difficult to decide, choose the description based on your best professional judgment then flag that sample in the "Remarks" column of the boring log for laboratory testing. Descriptions can be adjusted in final boring logs based on the results of laboratory testing.

Soils generally fall into one of two categories: coarse-grained (cohesionless) or fine-grained (cohesive). The ordered format for the description of these two categories of soils is as follows. In the written description each item of the description is separated by a semicolon. This description method varies slightly from that shown in Appendix C.

6.1.1 Coarse-Grained Soils

a. Adjective constituent: this is a secondary constituent or modifier defined on the basis of percentage by weight.
b. Main constituent (capitalized and underlined): the primary constituent defined on the basis of percentage by weight.

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c. Color; using the Munsel Color Chart if available.
d. Consistency; relative density determined by N value.
e. Moisture; relative moisture content given as dry, moist or wet.
f. Grain size; expressed as fine, medium or coarse, or range combinations of these.
g. Gradation; expressed as uniform, well graded, or poorly graded.
h. Grain shape; expressed as rounded, subrounded, subangular or angular.
i. Other minor constituents; defined on the basis of percentage by weight, listing those with the larger percentage first; expressed by the term “some” followed by the smaller percentage; expressed by the term “trace.”
j. Geologic origin; expressed in parentheses, such as Fill, Glacial Till, Topsoil, Alluvium, Loess, Weathered Bedrock, etc.

Examples of typical description are given below:

- Silty SAND; brown; loose; wet; fine-grained; uniform; rounded; some silt; trace clay (Alluvium)
- Sandy GRAVEL; light brown; dense; dry; fine- to coarse-grained; well graded; angular; trace sand and silt (Fill - Road Base)

6.1.2 Fine-Grained Soils

a. Adjective constituent: this is a secondary constituent or modifier defined on the basis of percentage by weight.
b. Main constituent (capitalized and underlined): the primary constituent defined on the basis of percentage by weight.
c. Color; using the Munsel Color Chart if available.
d. Consistency; undrained shear strength determined by N value or results of pocket penetrometer and torvane tests.
e. Moisture; relative moisture content given as dry, moist or wet.
f. Plasticity; expressed as non-plastic, low plasticity or high plasticity.

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g. Other minor constituents; defined on the basis of percentage by weight, listing those with the larger percentage first; expressed by the term "some" followed by the smaller percentage; expressed by the term "trace."

h. Geologic origin; expressed in parentheses, such as Fill, Glacial Till, Topsoil, Alluvium, Loess, Weathered Bedrock, etc.

Examples of a typical description are given below.

- Silty CLAY; gray; stiff; moist; high plasticity (Glacial Till)
- Clayey SILT; brown; soft; low plasticity; trace roots (Topsoil)

6.1.3 Constituent and Descriptive Terminology and Definitions

This section defines constituent and descriptive terminology most commonly used in the field when describing soils. The tables in this document are provided as a reference guide for the terminology used in the description of soils. The constituents of a soil are defined by particle size or gradation as shown in Table 6-1 Particle Size or Gradation.

As shown in examples of typical soil descriptions an adjective or modifier is given, then the main constituent, and finally minor constituents. These terms denote constituent proportions of the material being described. Table 6-2 Typical Soil Descriptions defines the percentage by weight for each of these terms used. The description in the field basically represents an estimate of the particle size and the percentages of the soil constituents.

The definitions in Table 6-2 are different than those provided in ASTM D 2488. The provided definitions are considered to be more practical for use in the field.

It is apparent from Table 6-2 that a material may have more than one main constituent. In this case use the word "and" in the description between the constituents; for example, SILT and CLAY.

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Table 6-1
Particle Size or Gradation

Constituent / Soil Type	Particle Size
Boulders	Greater than 9" in diameter
Cobbles	3" to 9" in diameter
Gravel	0.25" to 3" in diameter
Coarse	0.75" to 3" in diameter
Fine	0.25" to 0.75" diameter (No. 4 to 3/4")
Sand	.0029" to 0.25" diameter (No. 200 to No. 4)
Coarse	.08" to .25" diameter (No. 10 to No. 4)
Medium	.017" to .08" diameter (No. 40 to No. 10)
Fine	.0029" to .017" diameter (No. 200 to No. 40)
Silt	Less than .0029" diameter (< No. 200) low to nonplastic, cohesionless when dry
Clay	Less than .0029" diameter (< No. 200) cohesion and plasticity at all moisture contents

Table 6-2
Typical Soil Descriptions

Descriptive Term	Range of Percent by Weight
Main constituent (SAND, SILT, CLAY, GRAVEL, etc.)	Greater than 35%
Adjective (Sandy, Silty, Clayey, etc.)	20 to 35%
Some (Minor Constituent)	10 to 20%
Trace (Minor Constituent)	5 to 10%

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The N value determined from the Standard Penetration Test (SPT) defines the descriptive terms used to define the relative density of cohesionless soils or consistency of cohesive soils. Table 6-3 provides the correlations between N value and descriptive terminology for relative density or consistency of the soil sampled.

Table 6-4 shows the correlations between consistency, unconfined shear strength, N value, and hand test for cohesive soils.

Many soils exhibit textural characteristics such as stratification and inclusions. These characteristics also have a frequency component. To further aid in the completeness of the description of these types of observed characteristics in the field, Tables 6-5 and 6-6 show terms and definitions that have been included. Applying these terms with respect to their defined meaning should result in consistent and meaningful descriptions after returning from the field.

6.1.4 Labeling Soil Samples

All samples obtained in the field during an investigation shall be clearly labeled and stored to prevent loss or damage. Labeling is especially important because laboratory testing is performed by subcontractors. Selected samples cannot be tested if they cannot be identified upon arrival at laboratory. The following information shall be recorded on a label and affixed to the sample container:

- Client
- Project Name
- Project Number
- Boring or Test Pit Number
- Sample Type and Number
- Depth at which sample was taken
- Blow Counts for each 6-inch increment from the SPT

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Table 6-3
Correlations for Cohesionless Soils Between Compactness, D_R, and N Value

Compactness	Relative Density, D_R	N Value (SPT)
Very loose	< 0.15	< 4
Loose	0.15 - 0.35	4 - 10
Medium dense	0.35 - 0.65	10 - 30
Dense	0.65 - 0.85	30 - 50
Very dense	0.85 - 1.00	> 50

Table 6-4
Correlations for Cohesive Soils Between Consistency, Unconfined Shear Strength, N Value, and Hand Test

Consistency	N Value	Hand Test (Refer to ASTM D2488, Table 5 for alternative thumb criteria)	Unconfined Shear Strength (KSF)
Hard	> 30	Difficult to indent	> 4.0
Very stiff	15 - 30	Indented by thumbnail	2.0 - 4.0
Stiff	8 - 15	Indented by thumb	1.0 - 2.0
Firm (medium)	4 - 8	Molded by strong pressure	0.5 - 1.0
Soft	2 - 4	Molded by slight pressure	0.25 - 0.5
Very soft	< 2	Extrudes between fingers	0 - 0.25

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Table 6-5
Terms for Types of Stratification and Frequency

Term	Definition
Parting	0 to 1/8” (3 mm) in thickness
Seam	1/8” to 3” (3 mm to 75 mm) in thickness
Layer	> 3” (75 mm) in thickness
Pocket	Small erratic deposit usually < 12” (0.3 m) thickness.
Occasional	One (1) or less per 6” (150 mm) of thickness.
Frequent	More than one (1) per 6” (150 mm) in thickness.
Laminated	Having alternating partings or seams of different soil types less than 0.25” (6 mm) thick.
Stratified	As laminated, with layers thicker than 0.25” (6 mm).
Interlayered	Applied to layers of soil lying between or alternately with other layers of soil.
Intermixed	Applied to a random mixture of soil types.

Table 6-6
Terms for Types of Inclusions and Miscellaneous

Term	Definition
Cemented	Material grains bound together by a mineral material forming an intact mass not easily broken.
Welded	Material grains bound together by heat or pressure forming an intact mass not easily broken, common in volcanics.
Calcareous	Having appreciable quantities of calcium carbonate; this is determined by applying dilute hydrochloric acid to the material and observing an epervesant chemical reaction.
Ferrous	Having appreciable quantities of iron oxide.
Nodule	Small, more or less rounded body, generally harder than the sample matrix.
Fragment	Broken pieces of material. Describe size in mm.
Mottled	Irregular variation in colors.

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Each type of sample taken in the field requires different handling. The following provides additional detail in the labeling and handling of samples.

Standard Penetration Test (SPT) Samples. SPT samples are placed in sample jars. Labels shall be affixed to the jar. Do not put the above information only on the jar lid because the lid may get switched while someone is examining the sample. If labels are not provided or supply runs out, information may be recorded directly on the jar using a grease pencil. Some contractors prefer to use plastic "baggies" for SPT samples. These are only acceptable if approved in advance. Their use requires more careful handling of the samples.

Thin Wall Tube (TW) Samples. The sample information listed above shall be recorded on a label and affixed to the thin wall tube or written directly on the thin wall tube with a waterproof felt tip marker. TW samples shall be waxed as soon as they are removed from the ground, making certain that the wax has solidified before turning the tube over to wax the other end. If not available, the empty portion of the TW should be filled with rags or paper. Plastic caps shall be place over the ends of the tube and secured with tape, making sure to cover holes in the top of tube. The tubes shall be transported in an upright manner and shall not be subjected to jarring or other disturbance during transport. Tubes shall be protected from freezing in winter conditions or direct sunlight. Tubes that have been handled in a manner that may alter the undisturbed nature of the sample shall be reported to the project geotechnical engineer.

6.2 DESCRIPTION OF ROCK

There is no single standardized method for the description of rock. The degree of complexity of the description can be based upon the nature of the problem being studied and the relative importance of the rock-mass response. All the methods used in describing rock contain the same basic information used to characterize rock in the field.

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The following is the standardized basic format to be used when describing rock. The use of this standardized format will provide for the recording of all the basic information in a consistent and meaningful presentation. Each of the following items is separated by semicolons in the description:

- Rock type (all capital letters and underlined)
- Modifier (if distinctive)
- Color (from GSA color chart if available)
- Texture
- Grain size (or crystals)
- Weathering
- Strength
- Scratch hardness
- Other notable features
- Formation name (in parentheses)

Examples:

- <u>LIMESTONE</u> - oolitic; brown; fine- to medium-grained; fresh; strong; thickly bedded; vugs-pinpoint to 1" in size (Bethany Falls Limestone).
- <u>SANDSTONE</u> - Light brown; fine- to medium-grained; well sorted; rounded; slightly weathered; strong; hard; cross bedded (Blue Jacket Sandstone).
- <u>SHALE</u> - Black; fissile; slightly weathered to fresh; moderately strong; soft; calcareous; slightly fossiliferous (Lane Shale).

6.2.1 Explanation of Rock Type Classification and Descriptive Terminology

This section provides information on the classification of rocks and defines the basic descriptive terminology commonly used in describing various rock types. It is very important that prior to going to the field a literature search is done to review existing information on the geology of the project site. This will prepare the geologist or the

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engineer for the types of rocks present in the area and familiarize them with the general descriptive characteristics.

6.2.2 Rock Classification

Rocks are classified according to geologic origin. These origins have been divided into three families of rock. These are igneous, sedimentary, and metamorphic. All rocks fall into one of these families and are characterized as follows:

- Igneous - Rock that is made by the cooling and solidification of magma or lava.
- Sedimentary - Rock that consists of particles of sediment derived from older rock. The particles were transported by one of earth's external processes, deposited, and later cemented so as to make firm new rock.
- Metamorphic - Rock that consists of igneous or sedimentary rock that became deeply buried and was therefore subjected to high pressure and great heat, which changed the character of the rock.

The classification of sedimentary rock type is provided in Table 6-7. This table provides a basic guide for the field identification of rock types. It should be noted that most rock types represent a specific origin and composition. There are variations to these specific types that may represent a broad range. This results in very different looking specimens that may be the same rock type.

The rock identification guides presented in the following sections are the most straightforward. More detailed rock identification guides are located in the appendices of this guide.

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Table 6-7
Keys to the Identification of Rock Types

Rock Name	Composition	Critical Tests
1. Clastic Sedimentary Rocks		
Sandstone	Rounded fragments of sand size, 0.02 to 2 mm; binding cement.	Grains commonly quartz but other rock materials qualify in general classification.
Shale	Chiefly clay minerals.	Surface has smooth feel, no grit apparent, fissile texture splitting into thin layers or flakes.
Limestone	Calcite; may be even grained and crystalline.	Easily scratched with knife; effervesces in cold dilute hydrochloric acid.
Dolomite	Dolomite; may be even grained and crystalline.	Harder than limestone, softer than steel; requires scratching or powdering for effervescence in dilute hydrochloric acid.

6.2.3 Descriptive Terminology and Definitions

This section provides some of the common terminology used in the description of rock types and definitions of these terms. It is impossible to provide a complete listing, so it is recommended that during investigations where the rock description is required, individuals obtain an edition of "Glossary of Geologic Terms" to take to the field.

Modifiers. Rock type modifiers denote significant secondary constituents present in the rock. These may be significant in identifying a stratigraphic unit, such as the presence or absence of fossils or the presence of a specific fossil. The following list of modifiers for sedimentary rocks is provided for reference and understanding of descriptions by others:

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- Arenaceous - Abundant sand
- Calcareous - Abundant calcite, reacts to hydrochloric acid
- Ferruginous - Abundant iron
- Argillaceous - Abundant clay or shaley
- Fossiliferous - Abundant fossils
- Carbonaceous - Highly organic

Textures. Texture refers to the fabric form of the rock. Descriptive terms are generally related to the family of rock being described. Some common textures used in describing the sedimentary family of rock are as follows:

- Oolitic - Sand-like texture made up of round calcite accretionary bodies
- Fissile - Tends to break into thin flakes
- Conglomeritic - Poorly sorted with at least pebble-sized grains
- Sucrossic - Sugary
- Pisolitic - Pea-sized, rounded calcite accretionary bodies
- Earthy - Dull and dirt-like
- Vuggy - Voids caused by dissolution
- Platy - Laminar
- Blocky - Breaks into small angular pieces

Grain Size. Grain size relates to sedimentary rocks as described in Table 6-8.

Weathering. Weathering refers to a destructive process of erosion where a rock's character is changed from exposure to atmospheric agents at or near the surface. Changes in characteristics include color, texture, composition, hardness, strength, or form. The various degrees of weathering are defined by the relative terms listed in Table 6-9.

Strength. For engineering purposes, an estimate of approximate strength is made. The terms used to describe the rocks and how these terms relate to the approximate uniaxial compressive strength are shown in Table 6-10.

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Table 6-8
Sedimentary Rock Grain Size

Descriptive Term	Size Range	Recognition
Very coarse-grained	> 2.0 mm	Grains measurable
Coarse-grained	0.6 - 2.0 mm	Clearly visible to eye
Medium-grained	0.2 - 0.6 mm	Clearly visible with hand lens
Fine-grained	0.06 - 0.2 mm	Just visible with hand lens
Very fine-grained	< 0.06 mm	Not distinguishable with hand lens

Table 6-9
Various Degrees of Weathering

Descriptive Term	Recognition
Residual soil	Original minerals of rock have been entirely decomposed to secondary minerals, and original rock fabric is visible; material is friable. Rock weathered in place to a soil.
Extremely weathered	Original minerals of rock have been almost entirely decomposed to secondary minerals, although original fabric may be intact; material can be granulated by hand
Highly weathered	More than half of the rock is decomposed; rock is weakened so that a minimum 2 inch diameter sample can be broken readily by hand across rock fabric
Moderately weathered	Rock is discolored and noticeably weakened, but less than half is decomposed; a minimum 2 inch diameter sample cannot be broken readily by hand across the rock fabric
Slightly weathered	Rock is slightly discolored, but not noticeably lower in strength than fresh rock. Weathering is restricted to areas adjacent to joints.
Fresh	Rock shows no discoloration, loss of strength, or effect of weathering

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Table 6-10
Terms Used for Rock

Descriptive Term	Recognition	Approximate Uniaxial Compressive Strength (psi)
Extremely weak rock	Can be indented by thumb nail	35 - 150
Very weak rock	Can be peeled by pocket knife	150 - 700
Weak rock	Can be peeled with difficulty by pocket knife	700 - 3,500
Moderately strong rock	Can be indented 5 mm with sharp end of pick	3,500 - 7,000
Strong rock	Requires one (1) hammer blow to fracture	7,000 - 14,500
Very strong rock	Requires many hammer blows to fracture	14,500 - 35,000
Extremely strong rock	Can only be chipped with hammer blows	> 35,000

Scratch Hardness. In geology, hardness is defined as a mineral's resistance to scratching. The relative hardness is related to the Moh's Hardness Scale standard of ten minerals rated numerically 1 to 10, with ten being the hardest. The scale includes, from softest to hardest: talc, gypsum, calcite, fluorite, apatite, orthoclase, quartz, topaz, corundum, and diamond. In the field, relating Moh's scale to sample hardness is not practical. The terms defined in Table 6-11 shall be used to describe relative hardness.

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Table 6-11
Terms Used to Describe Relative Hardness

Descriptive Term	Recognition
Soft	Applicable only to plastic material
Friable	Easily crumbled by hand, pulverized, or reduced to powder; too soft to be cut by pocket knife
Low hardness	Can be gouged deeply or carved with a pocket knife
Moderately hard	Can be readily scratched by knife blade; scratch leaves heavy trace of dust and is readily visible after powder has been blown away
Hard	Can be scratched with pocket knife only with difficulty; scratch produces little powder; traces of knife steel may be visible
Very hard	Cannot be scratched with pocket knife; knife steel marks are left on surface

Other Notable Features. This part of the description includes any other features that should be noted. Generally, most descriptions will be made from rock cores rather than outcrops or exposures as in mapping. When describing rock cores, discontinuities are important and should be included in this part of the description. Discontinuities found in rock include faults, joints, foliation planes, veins, and bedding. These types of discontinuities are defined as follows:

- Fault - A fracture along which displacement has occurred due to tectonic activity.
- Joint - A fracture along which essentially no displacement has occurred.
- Shear - A plane or zone along which movement occurs in a direction parallel to the plane.
- Veins - A mineral filling of a fracture in host rock.
- Bedding - Contacts between sedimentary rocks.

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These discontinuities are often expressed in rock cores as surfaces along which the core is naturally (and not mechanically) broken. When documenting these types of features, follow the guide presented below with terminology that is mostly self explanatory, using the abbreviations shown following each descriptor.

Discontinuity Descriptors. All discontinuities shall be described on the boring log using the abbreviations below in the following order: "Type: dip, aperture, infilling, amount of infilling, planarity, roughness, spacing."

- Dip of fracture surface measured relative to a plane perpendicular to the core axis. Where core run(s) has numerous discontinuities, sets of discontinuities with dips in 10 to 20 degree spreads should be lumped.

- Type of discontinuity:
  - Bedding – B
  - Joint – J
  - Shear – Sh
  - Vein – V
  - Foliation– Fo
  - Fault – F

- Aperture of discontinuity (in inches):
  - Wide - W (0.5 - 2.0)
  - Moderately wide - MW (0.1 - 0.5)
  - Narrow - N (0.05 - 0.1)
  - Very narrow - VN (< 0.05)
  - Tight - T (0.00)

- Type of infilling:
  - Clay - Cl
  - Calcite - Ca
  - Chlorite - Ch

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- Iron oxide - Fe
- Gypsum/talc - Gy
- Healed - H
- None - No
- Quartz - Qz
- Sand - Sd
- Unknown - Uk

- Amount of infilling:
  - Surface stain - Su
  - Spotty - Sp
  - Partially filled - Pa
  - Filled - Fi
  - None - No

- Planarity:
  - Wavy - Wa
  - Planar - Pl
  - Stepped - St
  - Irregular - Ir

- Roughness of surface:
  - Slickensided - Slk - Surface has smooth, glassy finish with visual evidence of striations
  - Smooth - S - Surface appears smooth and feels smooth to the touch
  - Slightly rough - Sr - Asperities on the discontinuity surfaces are distinguishable and can be felt
  - Rough - R - Some ridges and side-angle steps are evident; asperities are clearly visible, and discontinuity surface feels very abrasive
  - Very rough - VR - Near vertical steps and ridges occur on the discontinuity surface

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- Spacing of discontinuities of the same set (example: foliation joints) (in feet):
  - Very wide - VW (> 10)
  - Wide - W (3 - 10)
  - Moderately wide - MW (1 - 3)
  - Close - C (0.2 - 1)
  - Very Close - VC (< 0.2)

6.2.4 Rock Coring

Borehole Setup. The designation, orientation, and general locations for the core borings shall be provided in advance of the field mobilization. The drilling contractor shall prepare a work space near the drill rig that allows for efficient handling and logging of the core. The location of the work area should permit direct viewing of the drill string so that drilling activities can be closely monitored, even while logging core.

Drilling Fluid. The drilling contractor will make every attempt to use water as the drilling fluid. If borehole stability problems are experienced drilling mud products and additives approved for use on this project are limited to soluble polymers (such as EZ Mud) prior to introduction into the drilling fluid. Drilling mud materials shall only be mixed with water.

Drilling fluid will be recirculated and waste drilling fluid shall not be permitted to flow over the ground surface. After use, the drilling fluid shall be contained in a catch basin and allowed to be containerized and transported off site for disposal at a landfill.

Core Barrels and Core Bits. The core barrel shall be a standard, ball-bearing, double or triple-tube swivel type “M” design or better with retrievable split inner tube. Core barrels shall be equipped with a bottom and side discharge bit and standard core lifters, and be at least five feet but no longer than ten feet in length.

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Core bits shall be diamond set or impregnated. The bit shape and configuration shall be selected by the drilling company. Selection shall be based on general knowledge of optimum core bits for the anticipated formations and the proposed drilling fluid system.

Replacement bits shall meet project specifications. The bit changes shall be recorded in the field logbook and on the boring log including the serial numbers, manufacturer and model of the new and replaced bit.

Logging Equipment. The geologist and/or driller shall arrive at the drill site with the equipment necessary to perform the work. The following checklist of core logging supplies and equipment is provided for reference and the geologist should coordinate with the driller to ensure all materials are available onsite.

Rock Core Logging Checklist:

- Hand Lens
- Knife
- Color Chart
- Field Notebook
- Rock Hammer
- Folding Wooden Ruler (marked in 1/10 feet)
- Pocket Scale (1/10 ft/mm)
- Spray Bottle
- Scrub Brush
- Protractor
- Acid Bottle
- Towels
- Water Bucket
- Filler Blocks (for lost recovery zones)
- Waterproof Markers

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Drilling Through Overburden. The project specifications will indicate the soil and rock samples to be collected during the field exploration program. It is intended that casing installed through overburden be removed after completion of the borehole.

Core Run Length and Core Recovery. When bedrock is encountered in the borehole, the first coring run should be less than or equal to five feet in length. Based on recovery through the initial run, the core runs should continue at a standard five foot length. In zones of exceptional recovery, core runs up to ten feet in length will generally be suitable, depending on the project specifications. The length of core run should be reduced whenever necessary to avoid core loss and to limit core disturbance, particularly when coring in soft or broken rock. Core run lengths may also be reduced when work progress is subjected to lengthy delays such as downtime or end of workday.

During coring, the drill speed, drill feed pressure, drilling fluid pressure, and length of the core run shall be controlled to give maximum core recovery. Grinding of the core shall not be permitted. If core barrel blockage is suspected, the barrel shall be withdrawn from the borehole and the core removed. The core barrel, bit, and other equipment shall be reviewed for proper working condition prior to advancement of the boring.

Borehole Stabilization. The driller shall place a reference mark on the wireline prior to core barrel withdrawal. When the core barrel is returned to the borehole, the reference mark will aid in evaluating possible sloughage of the borehole sidewalls. As a guideline, if more that approximately one-half foot of sloughed material is present at the bottom of the borehole, the hole must be cleaned prior to beginning the next coring run. If the rock is soft or broken such that pieces continually fall into the borehole, the hole shall be reamed and flush joint casing installed to a point below the broken interval. Alternatively, the hole may be grouted and redrilled to the completed depth prior to advancing the hole. The hole stabilization procedure shall be repeated as many times as necessary to keep the hole clean.

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Groundwater Conditions and Measurement. The water level in the borehole shall be measured periodically during drilling of a borehole, and before drilling has started for the day. Water levels shall also be measured after pulling the casing following completion of the borehole.

Any and all unusual water conditions, and elevations at which a gain or loss of water occurs in boring operations, shall be recorded completely on the boring logs. If water under excess pressure is observed, the drilling operations shall stop and the casing extended above the ground surface to contain the flow of water. The height of the water above the ground surface shall be recorded after allowing the water level to equilibrate. Once the water level is measured and recorded, the casing shall be lowered and sealed to allow further advancement of the borehole.

Driller's Report. The drilling contractor shall provide a complete, legible, and dated copy of the driller's activity records daily or at other agreed upon times. Separate records shall be made for each borehole. The drilling supervisor shall sign the report after confirming the accuracy of information provided for eventual billing purposes.

Borehole Supervisor's Report. A daily quantity sheet shall be filled out for each day's activities on the supplied Daily Activity Sheet.

Logging Format. The rock core will be logged on the project's standard 8.5 inch by 11 inch core boring log forms that are presented in an appendix to this document. Blank forms and sample logs are included in the Form appendix to this document. Logs produced in the field will be directly inputted into the GEOSYSTEM LD4 test boring log format. The field logs shall be neat, consistent and complete when submitted for software input.

The rock core shall be described as previously indicated. Discontinuities shall also be shown graphically within the appropriated column on the log. Any notations regarding suspected cavities and fissures, changes in the character of the drilling

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fluid or fluid return, and any other observations that could yield information on the rock formation should be included on the log.

Drill logs shall be completed as much as possible in the field including filling in all heading information. Additional information required on the field logs includes length of run, percent recovery, number of fractures in each 1-foot interval (fracture frequency) and Rock Quality Designation (RQD). Measurements of core length or borehole depth should be made to the nearest 0.10 feet. A tape measure or ruler that has 0.10 feet gradations shall be used.

Field information that is relevant, but for which there is no space on the log form, should be recorded in a project field book. For example, notes about the driller's production (minutes per foot) and down time shall be recorded in the project field book, with only the start and end times of each run and length of any interruptions noted in the appropriate column on the log form. Noticeable changes in the penetration rate during a core run shall also be recorded by depth in the field book. Computation of driller's production shall exclude time during a run that is not actually used for advancing the drill bit.

Rock Mass Classification. The following are the objectives of rock mass classification:

- Identify significant parameters influencing behavior of the rock mass
- Divide a particular rock mass into groups of similar behavior
- Provide basis of understanding characteristics of each rock mass class
- Relate the experience of rock conditions to other sites
- Derive quantitative data and guidelines for engineering design
- Provide a common basis for communication

6. DESCRIPTION AND CLASSIFICATION OF MATERIALS

A list of rock mass classification systems would include the following:

- Rock load classification method
- Stand-up time classification
- Rock Quality Designation (RQD)
- Rock Structure Rating (RSR)
- Rock Mass Rating System (RMRS)
- Q - System
- Size strength classification
- ISRM classification

For this project in the field, the RQD system shall be used. ASTM D6032-02 Standard Test Method for Determining Rock Quality Designation (RQD) of Rock Cores is presented in Appendix F for reference.

Rock Quality Designation. The RQD shall be calculated for the rock cores and recorded on the log form. RQD shall be performed at the time the core is retrieved, and still in one-half of the split liner, to avoid the effects of post removal slaking and separation of core along bedding planes, as in some shales. Length measurements of the core pieces shall be taken along the centerline of the rock core.

The RQD of a rock is evaluated by determining the percentage recovery of core in lengths greater than twice its diameter. The index was first applied solely to NX core, usually 2.125 inches in diameter, the percentage core recovery being modified to reject from the recovered category any fragments less than four inches in length. If the fractures run longitudinally along the core axis, the interval shall be considered highly fractured and unsound even if the core length along the centerline may be longer than four inches. The RQD number is then expressed in percentage form. The description of the rock quality corresponds to the RQD value as shown in Table 6-12 Rock Quality Designation (RQD).

6. DESCRIPTION AND CLASSIFICATION OF MATERIALS

Table 6-12
Rock Quality Designation (RQD)

RQD (%)	Description of Rock Quality
0 - 25	Very Poor
25 - 50	Poor
50 - 75	Fair
75 - 90	Good
90 - 100	Excellent

Core breaks caused by the drilling process shall be fitted together and counted as one piece. Drilling breaks are usually evident by rough fresh surfaces. It is critically important to log the true in situ discontinuities of the subsurface rock. Mechanical breaks caused by drilling or handling should not be included in the fracture frequency count or the RQD determination. Mechanical breaks in rock core will appear fresh, fit together tightly, and have no filling.

The following criteria can be used as a guide to identify natural breaks:

- A rough, brittle surface with fresh cleavage planes in individual rock minerals indicates an artificial or mechanical fracture. The two pieces of core generally “lock” together when manipulated.
- A generally smooth or weathered surface with a soft coating or infilling materials, such as talc, gypsum, chlorite, mica, calcite, or iron staining indicates a natural discontinuity and not a mechanical fracture.

Note that if in doubt about a break, whether natural or mechanical, it depends on the project goals whether it is conservative or misleading to consider it a mechanical or natural beak. For a building foundation, it may be conservative to assume an unknown break is natural. However, for a tunnel excavation or a ripping estimate it may be conservative to assume an unknown break is a mechanical break. Make sure you think through what the rock core logging means to the project and discuss with senior technical project personnel.

6. DESCRIPTION AND CLASSIFICATION OF MATERIALS

Appropriate lengths or rock core described as fresh or slightly weathered rock are to be included in the RQD count. Qualifying lengths of moderately weathered rock are to be included although the RQD should be marked by an asterisk to show a reduced state of soundness. Therefore, the RQD will provide an indication of the rock quality with respect to the degree of fracturing, while also noting its lack of soundness. Residual soils, extremely weathered, and highly weathered rock should receive a zero value in the RQD calculation.

Retrieval of Core Liner. Generally, the driller will remove the core liner from the inner core barrel immediately after recovery and while under the field geologist's observation. Removing the liner shall be done is such a way as to prevent disturbance or breaks in the rock core. Pounding of the core barrel to force the liner loose shall not be permitted. The core liner shall generally be extracted by pumping water into the inner tube to push the split liner out. This shall be done with the inner barrel close to horizontal in order to limit disturbance of the core.

Core retained in the shoe of the core barrel shall be extracted with care to reduce mechanical breakage. Core from the shoe should be placed in its proper position either in the liner or adjacent to the end of the liner for subsequent processing of the core.

After retrieval, the core liner should be opened promptly to assess recovery. The amount and quality of recovery will aid the drillers in making adjustments, if necessary, to optimize core recovery during the next run.

Core Logging. The core shall be measured and logged while remaining within the core liner to the maximum extent possible. The person logging the core should consider the accurate description of recovered core and a technically sound interpretation of non-recovered core to be their primary focus during rock coring operations. The interpretations of core loss should be based on observations of drilling characteristics or core appearance, and after consultation with the driller. The interpretative reason for the core loss should be noted on the core logs.

6. DESCRIPTION AND CLASSIFICATION OF MATERIALS

The individual logging the rock core should keep a log book with the following items: beginning depth, start time of run, ending time of run, and depth at the end of run. During the core run, field notes should be kept with comments on drilling. This shall include loss of or changes in rate of return of drilling fluid, changes in color of drilling fluid, bit drops, changes in rate of advancement, bit changes, addition of drilling mud, or additives to drilling fluid, etc.

When the core run is retrieved and removed from the inner barrel, make sure the driller's helper always lays the core with the top on the left side as viewed by the core logger. While the core is in the split, determine the amount of recovery and the RQD for the run. Highly or extremely weathered rock in the core is not included in the measurement of RQD. Then describe the rock according to the order of items previously discussed.

Rapid drilling progress or other factors may not allow sufficient time for proper handling, examination, and logging of the core. At such times the field exploration manager should be consulted to possibly direct the drilling crew to standby status until the core logging operations can be brought under control. ASTM D2113-99 Standard Practice for Rock Core Drilling and Sampling of Rock for Site Investigation is presented in Appendix D for reference.

Core Storage in Boxes. Investigations involving rock coring shall require wooden boxes. Cardboard boxes shall not be used. The core box should be filled from the upper left hand corner to the lower right as you view the box with the lid away from you (like reading a book). Core pieces shall be fitted into the core box with fragments arranged as they would naturally have occurred.

Two wooden spacer blocks (1 inch thick) should be placed in the core box at the start of each run indicating the depth and run number. A spacer should be inserted for each lost core zone equal to the length of the core loss with the depth interval clearly marked on it. Mechanical breaks should be noted on the core by placing an "M" above and below the break. When samples of core are removed for laboratory

6. DESCRIPTION AND CLASSIFICATION OF MATERIALS

testing, a Styrofoam spacer should be inserted with the core interval, laboratory sample number and laboratory test clearly labeled. Core left in the borehole during retrieval and recovered on the next run should be added to the previous run.

Depths in feet and tenths of a foot shall be clearly marked on the top of both box ends for each core compartment. Filler blocks shall be marked in like manner at the top and bottom of the lost interval and shall be labeled with the designation “Core Loss.” All spacer and filler blocks shall be marked with black waterproof marker. The lettering on the blocks and the box ends shall be easily readable from a distance. Labels, as stenciled on the core boxes, shall be completely filled out with a black waterproof marker. Labels shall appear on the inside and outside faces of the top lid and on the left outside end of each box. Fine-tip markers may be necessary to legibly complete the side label. ASTM D5079-02 Standard Practices for Preserving and Transporting Rock Core Samples is presented in Appendix E for reference.

The core boxes should be labeled with project name, location, boring number, box number (1 of …., etc.), and footage (from …. to ….). This information should be written on the inside of the box lid, on the outside of the box lid, and on the left outside end of each box. In addition, the upper left hand corner of the box should be labeled as “Top” and the lower right hand corner of the box should be labeled “Bottom.”

Core Box Care and Transport. At the drill site, the core boxes shall be lined up in a safe, out of the way area, preferably on boards or planks, and kept clean and dry. When core is moved it shall be done carefully to prevent disturbance, breakage, or spilling of the core. Careful driving shall be exercised when transporting cores. Core boxes shall be secured in the truck bed to prevent sliding during transport across rough terrain. Core boxes shall be placed on pallets in a DPW-designated holding area in the core storage location at the Southport Wastewater Treatment Plant in Indianapolis.

6. DESCRIPTION AND CLASSIFICATION OF MATERIALS

Core Review. A timely review shall be performed of draft logs and core after it has been transported to permanent storage. The logs shall be checked for accuracy and conformance to the required log format. Changes to the draft logs shall be made legibly with a red-colored pen. Missing and incomplete information shall be added as necessary.

When samples are taken for testing, filler blocks sufficient to replace the sample length shall be used. This will permit replacement of the sample, if available, back into the core run after testing is completed.

Core Photography. Core photographs shall be taken prior to placement of each boring's core into the long-term storage area. Photographs shall be taken of the core packed in the core boxes using a digital camera.

Information such as borehole number, depth, box number, etc. shall be clearly displayed. The cores shall be lightly sprayed with water to bring out the color. A color patch shall be place next to the cores as reference color to identify color distortion during film processing. A tape measure shall be place along the length of the cores from one end of the box to the other. It shall have relatively large, high contrast markings to be visible in the photograph. Photographs shall be developed in a 3 inch by 5 inch size with matte, not glossy, finish.

Final Core Storage. After final photographs are taken and available laboratory samples have been returned to the core box, the core boxes shall be placed in order on pallets and moved into position in the long-term core storage area designated by DPW at the Southport Wastewater Treatment Plant in Indianapolis.

6. DESCRIPTION AND CLASSIFICATION OF MATERIALS

Borehole Backfill. Following completion of drilling, sampling, testing, water level measurements, and other observations in a boring, the boreholes that are not being completed as piezometers shall be backfilled using a cement-bentonite grout mix as specified. Generally, the grout mix shall be pumped into the borehole through the drill rods or other suitable pipe which has been placed to the bottom of the borehole. When the mixture comes to the surface, the rods can be withdrawn. As rods or pipes are withdrawn, additional cement-bentonite mixture shall be added to make up for the volume lost.

The standard grout mix shall consist of equal parts cement and bentonite mixed with no more water than is required for proper placement. Mix cement and water first, slowly adding bentonite. The amount of bentonite or water used may be varied somewhat to control consistency and workability of the mix.

A field record shall be kept for each boring to document the method and procedures followed for backfilling.

7. OTHER FIELD INVESTIGATIONS AND TESTING

Field investigations for projects often employ methods of investigation other than the subsurface drilling and sampling of materials. These methods either confirm subsurface conditions defined by the borings or provide additional parameters necessary for design. Some of these methods require direct involvement in the performance, collection of data and interpretation of the method used, while other methods will be performed by subcontractors. It is important that the field representative have some understanding of these methods so that assurance methods are performed properly and that the obtained data is reasonable. The following sections provide either a "how to" guide or a general explanation of the method, equipment and data to be acquired.

7.1 PERMEABILITY TESTING

Permeability values will be obtained for subsurface strata by conducting packer tests throughout the rock column. The general arrangement of equipment used in pressure testing is shown in the Figures section. One of two general procedures is used, depending on field conditions. In general, we anticipate that the rock quality and permeability will be such that the hole will be drilled to the final depth, circulating clean water to clean the walls of the fines, and then tested. If an organic drilling fluid has been used, Johnson's "Fast-Break" or an equivalent acceptable to the Engineer shall be added to water and circulated throughout the borehole for an adequate period of time prior to pressure testing. Testing proceeds in sections from the bottom up using two packers (one above and one below test section). In addition, if a wireline system is used, a packer in the drill rods is also used. In general, packer spacing depends on rock quality and permeability. For this project we anticipate using a 10 foot interval.

The alternative procedure is used where the driller can not maintain an open hole due to poor rock quality, or can not maintain circulation of the drilling fluids to flush the cuttings from the hole. In these cases, the driller should grout the hole or install casing prior to advancing the hole. When this occurs a single packer test shall be

7. OTHER FIELD INVESTIGATIONS AND TESTING

performed. This entails placing a packer some distance above the zone where drilling fluids were lost or caving is occurring.

The packers are expanded with air (nitrogen), and water under pressure is introduced into the hole. The packer tests will be performed at a maximum of pressure (baseline pressure) of 0.5 pound per square inch (psi) per foot of overburden cover plus 1 psi per foot of rock cover above the mid-point of the test interval. Testing of an interval consists of five pressure steps. The tests are run sequentially at 0.5, 0.75, 1.0, 0.75, and 0.5 of the baseline pressure. To calculate the true vertical depth for an inclined boring, use the following:

$$\text{True Vertical Depth} = D(\cos \propto)$$

Where D = depth to midpoint of test interval as measured down borehole
$\propto$ = angle from vertical in which the boring is drilled

Each pressure step should be run for a minimum of 5 minutes after reaching equilibrium. Readings of flow rates are made at 1 minute intervals. If there is no water take during the buildup of pressure for the first three pressure steps, then the final two step-down tests are eliminated.

Some general comments and suggestions regarding pressure testing are as follows:

- Pressurize up the packer system at a low pressure prior to lowering into borehole to check for leaks.
- Seat packers in borehole where rock appears to be unfractured.
- Ensure that there is overlap from one test to the next.
- Do a bucket test on flowmeters to ensure that they are functioning properly and reading of the flowmeter units is understood.
- If there is an open borehole nearby a boring that is being tested, the water level in the boring should be monitored periodically during the testing to determine if there is a hydraulic connection.

7. OTHER FIELD INVESTIGATIONS AND TESTING

- Leaking around the packers will result in water rising to the surface, dramatic changes in flow rates during a test, or a drop in pressure. If leakage around the packers is detected, stop the test, deflate the packers and move them to a different location after checking the field log for fracture locations.
- Make sure there is an adequate supply of water and air to complete the test prior to starting each test.
- Transducers are to be used in addition to surface gauges in acquiring pressure data.

The elapsed time and volume of water pumped are recorded. The test curves are plotted as flow versus pressure, which permits evaluation of changes in the rock mass during testing.

Notes on Water Pressure Packer Testing

The borehole water pressure (packer) testing is done to determine the permeability for the rock mass. The permeability is usually expressed as a velocity or as Lugeons (named after a French Engineer), defined as the water flow in liters/min per each meter of borehole at one bar pressure. This is not a true permeability because fractured rock is not a true porous medium, but it is a relative measure that gives an indication of the potential leakage from a water conveyance structure.

The test is conducted by isolating a section of the borehole, generally with inflatable packers, and pressurizing it with clean water and recording effective driving pressure and the flow rate. Each test should be continued until the flow and test pressure have stabilized over three consecutive measurements. They are never completely stable and may drift up and down somewhat between each measurement, but there should be no trend. The three important parameters to calculating the permeability are the pressure in the test interval, the flow rate, and the static water level in the borehole. The static water level is important because it does not contribute to the driving energy differential causing the flow: the actual driving pressure for the water

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flow is the pressure in the test interval minus the head of the groundwater level above, which is a balanced or static force.

The packer set-up can be a single packer isolating the entire section of the hole below the packer. This is generally done with a wireline drill system: a section of hole is drilled, the core barrel removed, the rods pulled back through that section, and the packer sent down to seal it for the testing. It can also be done with a straddle (double packer) set-up. The straddle packer is generally used when the drilling of the hole has been completed before testing: the drill rods are pulled back as the straddle packer is used to isolate successive intervals, or the drill rods are removed completely before the packer assembly is inserted on a pipe string.

1. The test interval length can be varied. Usually about 3 meters (10 feet) is acceptable. In very impermeable sections of the hole (those with few, tight joints) an interval of about 6 meters (20 feet) can be used. Portions of the hole over which there were large water losses during drilling should be tested using an interval of 1 to 2 meters (5 feet or less).

2. The usual upper limit to pressure for the testing is one psi per vertical foot of rock cover over the test interval plus one-half psi per foot of overburden cover. When doing very shallow tests it is best to keep the pressure low.

3. Each test at depth is usually repeated in five segments at three ascending then descending pressures. Calculate the maximum pressure to be used and then 75% and 50% of the maximum pressure. Do the test first at 50%, then 75%, and then at the full maximum pressure. Then do the test at 75%, and 50% again. If the results at 75% and 50% for the second time vary from those the first time, it indicates the water testing is changing something in the rock, such as washing away loose material. When doing a shallow test where the test pressure is very limited, the test might only be done once depending on the accuracy of the pressure indicating instrument.

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4. In example, if the test depth were from 12 to 15 meters in a vertical hole the maximum pressure would be about 4 × 13.5 or 54 psi. If the pressure gauge is accurate enough to read these, one would test at 27, 40.5, and 54 psi. Near the surface of the rock one would only test at two different pressures, or even only one just below the top of rock (at the minimum reading of the instrument).

5. One can monitor the test pressure with either a pressure gage at the surface or using a piezometer (transducer) in the test interval. The transducer is preferred and required for this contract because of its superior accuracy. In any case, the surface gauge should be placed as closely as possible to drill rods at the top of the hole to minimize the friction losses in the piping between the gauge and the test interval.

6. To calculate the pressure in the test interval (P_{TX}): gauge pressure + water column pressure – friction losses. The water column is the vertical distance from the gauge down to the middle of the test interval. The friction losses are the pressure loss due to friction in the piping between a gauge at the surface and the center of the test interval. These are only important at high flows or when the packer piping is narrow and restricts the flow. Sometimes when the ground is very permeable (such as limestone with joints opened by solution or in some volcanic rocks with open structure) the packer and piping can be the greatest restriction to flow. In such a case, a transducer in the test interval would never read higher than the static groundwater level, no matter how high the pressure registered on the gage at the surface.

7. Friction losses in the packer system only have to be accounted for if one is testing using a gauge at the surface to monitor pressure. If one has a transducer in the test interval, the test interval pressure (P_{TX}) is measured directly so the friction losses are included and do not affect the measurement. This is why we prefer to use a downhole transducer.

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8. The groundwater column is the vertical distance from the water table to the middle of the test interval. This is subtracted from P_{TX} to obtain the effective test pressure, the actual differential pressure that is causing the water flow into the test interval. It is this that is entered into the formula to calculate the interval permeability.

9. If one is testing using only a pressure gage at the surface and not a transducer in the test interval, the friction losses have to be tested for by laying the packer testing equipment assembled just as it would be in the hole but level on the ground and pumping water through it at different rates. There is very little loss in N sized or larger drill rods. Therefore, if a wireline system is being used, the friction loss will be exclusively in the narrow pipe going through the packer. This allows only one rod to be used for the friction loss test. If narrow pipes are used to suspend the packer in the hole, the friction loss test should be repeated for various lengths of pipe up to the maximum depth of the testing. The gauge pressure is read for each flow rate and graphed.

10. The packer must be inflated to at least 50 to 100 psi over the test pressure and at higher pressures at greater depths below the groundwater because the water pressure in the hole must be overcome for the packer to expand and seal the interval. The packer must never be fully inflated outside of a hole or piece of drill rod. It is designed to have the external support or confinement and may burst if inflated without confinement.

11. When conducting a test segment, raise the test pressure and flow rate into the hole by adjusting the pump speed and the bypass valve until the pressure is steady. Then determine the flow rate at one minute intervals for at least 5 minutes. The water meter reads in volume, so the flow rate is calculated as the change in volume over the one minute interval. When the pressure and flow are nearly constant for 5 minutes, that test segment is completed.

7. OTHER FIELD INVESTIGATIONS AND TESTING

12. The test cycle when using a wireline set-up is a follows:

    a. The drill rods are pulled back to about 3/4 meter above the interval to be tested (the upper packer is about 3/4 meter long).
    b. The packer assembly with the inflation tube attached is lowered into the drill rods through the seal box until it stops in the bit, and the above ground components are assembled and attached to seal box.
    c. Start the test with the recirculation valve fully open and bypassing the water back to the tank or mud pit. Slowly close the recirculation valve until the desired pressure is read on the gauge or transducer.
    d. Record the flow and pressure at one minute intervals until they are reasonably constant for three to five minutes.
    e. This is repeated for each pressure 50%, 75%, 100%, 75%, and 50% again of the maximum pressure. During the descending phase of the testing, the second tests at 75% and 50% of maximum pressure do not have to be exactly at the same pressure as the first test, but should remain close. It is generally impossible to get the pressure exactly back to that of the original ascending test values.

13. The following data shall be recorded on the forms shown in Appendix G:

    a. The hole information including boring number, test date, total depth and angle from vertical.
    b. Depth to groundwater. This should be measured as long as possible after the drilling is completed to allow it to equilibrate. If the equilibration period is short, it should be measured again at least 24 hours after the testing is done to confirm the first reading.
    c. The height of the gauge above the ground. This plus the vertical depth to the center of the test interval are added to give water column head or pressure.

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d. The pressure when it is steady. It may drift up and down a little between individual one minute readings but one should wait until they average the same over the test period.

e. The water meter reading and pressure at one minute intervals until the water take is approximately steady for three to five minutes. Again, the recorded data will not be perfectly steady but drift up and down with each reading around some average. At the end of the period the pressure and flow used in the calculations for permeability will be the averages over the steady period.

14. The first page of the pressure test form is used to calculate the test pressure as follows:

a. Test Interval is the depth measured along the borehole to the top and bottom of the test interval.

b. D = vertical depth to the middle of the test interval measured.

c. D_{WL} = vertical depth to groundwater.

d. For doing the calculation on the first page for a borehole drilled at a low angle (far from vertical), D and D_{WL} need to be corrected for non-verticality. D = the depth along the hole × cosine (borehole angle from vertical) and D_{WL} = the depth to groundwater measured along the hole × cosine (borehole angle from vertical). At less than 20˚ from vertical, the corrections are small and not necessary.

e. P_{BL} = Maximum pressure to be used in the test interval.

f. P_{TX} = pressures measured at the middle of the test interval required for the steps in the tests at 0.5, 0.75, and 1 × P_{BL}.

g. Some transducers read out directly in psi. Others read out in Hertz and come with a linear calibration of two constants, R_0 and C, to pressure. R_0 = the transducer reading at atmospheric pressure. C = the transducer constant varies between instruments and should come on a calibration sheet with the transducer. For the linear calibration when R_1 = the transducer (piezometer) reading at P_{TX}: To calculate R_1

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for any P_{TX}, $R_1 = R_0 + P_{TX} / C$. To calculate P_{TX} for any R_1: $P_{TX} = C (R_1 - R_0)$. R_1 = transducer reading at zero pressure, at the surface.

h. Some transducers come with a quadratic calibration. If this is the case, the data can be used in Excel to derive a linear calibration which is much easier to use in the field with no significant loss in accuracy.

i. P_{GX} = the gage pressure when the test interval pressure is P_{TX}. $P_{TX} = P_{GX}$ + pressure from the weight of the water column between the gage and the middle of the test interval.

j. When testing without a transducer in the test interval, use gage pressure P_{GX} to control the pressure in the test interval P_{TX}.

k. When there is a transducer in the test interval, use the transducer reading R_1 to control the pressure in the test interval P_{TX}.

l. The interval does not have to be tested at the exact P_{TX} pressures calculated on the first sheet. Pressure cannot be controlled that closely. Therefore, to be considered a valid test the pressure can be between P_{TX} plus or minus 10% or P_{TX} +/- 0.1 P_{TX}.

15. The second and third pages of the form are used to collect the data during the test. The graph is used to determine if the tests are affecting the borehole permeability.

7.2 DOWNHOLE VIDEO-LOGGING

Up to eight boreholes will be video-logged to view and document the in-situ orientation and characteristics of fractures, bedding planes, joints and solution features. Video- logging will be conducted and reported by others using acoustical televiewer (ATV) instrumentation. The drilling contractor shall assist the video-logging consultant as specified in Appendix B - Drilling Consultant Scope of Work with Black & Veatch.

8. HEALTH & SAFETY PROCEDURES

This section establishes health & safety procedures for project specific safety guidelines and procedures for activities performed by Black & Veatch Corporation employees. These procedures are based on existing site conditions and data. Activity Hazard Analysis and Emergency Action Plan sections are also included in this section.

It is the policy of Black & Veatch to provide all employees with a safe and healthful work environment, as free as possible from recognized hazards. It is also policy to maintain and actively support a comprehensive Employee Safety and Health Program. Additional policies, practices, rules, and regulations are outlined in the Black & Veatch Corporate Safety Manual entitled *Focus on Safety and Health.*

These health and safety procedures in addition to the Corporate Safety Manual, are applicable to Black & Veatch employees within the work limits of the contract. Subcontractors to Black & Veatch will be required to prepare Health & Safety Plans that are specific to their operations.

8.1 ACTIVITY HAZARD ANALYSIS

The items listed below are hazards that all Black & Veatch employees must be aware of prior to accessing the job site. The hazards described below do not represent all hazards that may be encountered on the job site, but outline the major hazards associated with performing the work. If additional hazards are encountered, Black & Veatch personnel shall contact the Project Manager or Corporate Safety Manager for assistance and additional Activity Hazard Analyses will be completed.

The site-specific hazards include the following:

- Site conditions may expose employees to uneven terrain. Employees are expected to walk carefully and slowly to avoid losing their balance. No running is allowed on the site, except when necessary in the event of an emergency.

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- Employees may be exposed to traffic because borehole locations will be in public right-of-ways adjacent to streets. Black & Veatch personnel are to wear orange vests with reflectors when working along roadways.
- Employees, no matter what task, always have the potential to injure their backs. All lifting that is to be done must be performed correctly by using their legs. If the object is heavy or oblong, assistance shall be used.
- Personnel will use the proper personal protective equipment (PPE), which will include hard hats, safety glasses, sleeved shirts, full length pants and leather work boots. Personnel will not wear loose fitting clothing or other items which have an increased potential to get caught in moving parts.
- Slip, trip, and fall hazards will be mitigated as they are recognized. Good housekeeping practices will be followed to reduce clutter near the work area. Only essential, properly maintained equipment will be used within the work area.
- Appropriate fall protection will be available. Fall protection will be employed whenever a crew member's heels are 4 feet or more above the deck or ground level.
- Grouting operations may expose employees to eye and skin ailments if direct contact to the grout is made. All employees are to be made aware of the hazards of grout, both in dry and mixed states. Material Safety Data Sheets (MSDS's) shall be provided by the drilling Contractor for review by employees.
- All portable energy sources will be operated and maintained in accordance with manufacturer's guidelines.
- During pressure testing and grouting operations that Black & Veatch will observe, exposures to pressurized hoses and pipes will be imminent. Black & Veatch employees are expected to stay away from pressurized hoses and pipes as work warrants.
- During groundwater monitoring, personnel will carefully open and close protective covers to protect hands and feet from injuries.

8.2 EMERGENCY CONTACTS

The following lists Black & Veatch personnel and client representatives to be notified in case of emergency for this project:

Black & Veatch
8720 Castle Creek Parkway, Suite 210
Indianapolis, Indiana 46250

- Manager of Safety and Health: Shawn King (913) 458-3329
- Project Manager: Donnie Ginn (317) 570-8331
- Project Engineer John Trypus (317) 570-8331

Indianapolis Clean Stream Team
151 N. Delaware St., Suite 900
Indianapolis, IN 46204

- Deputy Program Manager: David Klunzinger (317) 327-8720

Specific procedures to be followed in the instance of medical, fire or weather related emergencies are outlined below for this project.

The Black & Veatch Site Representatives shall make arrangements for Black & Veatch personnel with a local clinic and the nearest hospital in case of a Black & Veatch medical emergency. This information is included on the emergency routes and procedures.

<u>Preplanning</u>

Arrangements will be made with the local response community (i.e., fire department or local response services, etc.) for the response organization to respond to Black & Veatch personnel emergencies that may occur during site operations. The local

8. HEALTH & SAFETY PROCEDURES

response community will be provided with information regarding site activities, including the types of operations being conducted at the site, the location of the work zone, and any other relevant information that may be necessary for an appropriate response. Such information will be provided to a supervisory level representative of the emergency response organization prior to the commencement of site operations.

Reporting Emergencies

The Black & Veatch personnel on site will assess the Black & Veatch emergency and determine if onsite resources are capable of responding to the emergency without exceeding the level of training and resources available. If offsite emergency response organizations are needed, they will be notified in accordance with the preplanning arrangements.

Accident / Incident Reporting

In the event of a serious injury (definition below), fatality, property damage, accident, or any damaging fire, the Project Manager shall be immediately notified regardless of the day or hour. This reporting requirement is in addition to the requirements outlined in the above paragraph.

A serious injury is defined as any injury that requires medical treatment beyond first aid (as defined by OSHA in the publication *Recordkeeping Guidelines for Occupational Injuries and Illnesses*), any trip to the hospital or doctor's office or any single incident where two or more employees are injured.

Medical Emergencies

Prior to the start of work, arrangements for Black & Veatch personnel will be made for medical facilities, ambulance service, and medical personnel to be available for prompt attention to the injured.

8. HEALTH & SAFETY PROCEDURES

If a Black & Veatch employee is injured or becomes ill, personnel identified as trained in first aid and CPR will be notified immediately. First aid and CPR will be administered immediately. In all cases, treatment for shock should be considered. After the victim has been attended to, the Project Manager will be notified. Depending on the severity of the injury or illness, the medical emergency response organizations may be notified. If the Black & Veatch victim is transferred offsite, a responsible person shall accompany the victim, if feasible.

Emergency Contact List

Black & Veatch	(317) 570-8331
Indiana University Hospital	(317) 274-5000 or **911**
Indianapolis Fire Department	(317) 327-6041 or **911**
Indianapolis Police Department	(317) 327-6400 or **911**
Poison Control Center	(800) 942 5969 or **911**
Ambulance	**911**

Emergency Medical Treatment

Indiana University Hospital	(317) 274-5000 or **911**
550 University Boulevard	
Indianapolis, IN 46202	

APPENDIX A

FORMS

LOG OF BORING

BLACK & VEATCH
CONSULTING ENGINEERS

LOG OF BORING

BORING NO. 4

SHEET 5 OF

CLIENT 1	PROJECT 2	PROJECT NO. 3
PROJECT LOCATION 6	COORDINATES 7	ELEVATION (DATUM) 8
TOTAL DEPTH 9	DATE START 11	
SURFACE CONDITIONS 10	DATE FINISH 12	

SAMPLING						
SAMPLE TYPE	SAMPLE NUMBER	SET 6"	2ND 6"	3RD 6"	N VALUE	SAMPLE RECOV.
19A	20A	21A	22A	23A	24A	25A
CORING						
CORE SIZE	RUN NUMBER	RUN LENGTH	RUN RECOV.	RQD RECOV.	PERCENT RECOV.	RQD
19B	20B	21B	22B	23B	24B	25B

DRILLING CONTRACTOR 13

DRILL RIG 14	DRILLER 15	INSPECTOR 16	DATE
CHECKED BY 17	DATE	APPROVED BY 18	DATE

DEPTH IN FEET	SAMPLE TYPE	LOG	CLASSIFICATION OF MATERIAL	REMARKS
26 1	27		29	30
2				
3	28			
4				
5				
6				
7				
8				
9				
0				
1				
2				
3				
4				
5				
6				
7				
8				
9				
0				
1				
2				
3				
4				
5				
6				
7				
8				
9				

ST-035B

SAMPLE FIELD (PRELIMINARY) LOG OF BORING

BLACK & VEATCH — **FIELD (PRELIMINARY) LOG OF BORING** — BORING NO. BV-1 — SHEET 1 OF 2

CLIENT: MidAmerican Energy Holdings Co.	PROJECT: Green Bay Power Station		PROJECT NO.: 7652
PROJECT LOCATION: Green Bay, Wisconsin	COORDINATES: N 278,580 E 2,465,330	ELEVATION (DATUM): 657.2 (NGVD)	TOTAL DEPTH:
SURFACE CONDITIONS: Grass Covered, Nearly Level			DATE STARTED: 09-10-99 / DATE FINISHED: 09-12-99
DRILLING CONTRACTOR: Patrick Drilling			DRILL RIG: Truck Mount CME 75
DRILLER: Jerry Copak	LOGGED BY: DD Marlow		

Sample Type / Core Size	Sample Number / Run Number	Set 6 Inches / Run Length	2nd 6 Inches / Run Recovery	3rd 6 Inches / RQD Recovery	N Value / Percent Recovery	Sample Recovery / RQD	Depth in Feet	Classification of Materials	Remarks
SPT	1	3	4	5	9	1.5	1–3	Silty CLAY; light brown; stiff, moist; high plasticity; some sand; trace roots (Topsoil)	Boring advanced using 4 1/4" I.D. Hollow stem augers; SPT sampler driven using 140 lb Hammer using 30" drop; 2 1/4 turns on cat head.
TW	2					1.8	5–7		
SPT	3	5	7	5	12	1.3	10–12	Silty SAND; light brown, medium dense; wet; fine to medium grained; poorly graded; rounded (Alluvium)	H_2O @ 8.5'
SPT	4	20	50	–	50+	1.0	15–16	Grading very dense	
							19		Hard drilling @ 19.0' - gravel & cobbles
2 1/2"	1	5.0 (20.0–25.0)	3.0	–	60	–	20–25	BOULDERS AND Cobbles; consisting of Granite; Limestone, and basalt; angular to rounded; some sand & gravel	Auger refusal at 20.0'; Continue boring from 20' using HQ double tube core barrel w/ diamond bit and water as drilling fluid. 3 25/32 O.D.
2 1/2"	2	5.0	5.0	4.0	100	80	25–29	LIMESTONE; light gray; slightly weathered to fresh; fine grained; strong; very hard, massive; with occasional shaley laminations (Plattsburg Formation)	

SAMPLE FIELD (PRELIMINARY) LOG OF BORING CONT.

BLACK & VEATCH

FIELD (PRELIMINARY) LOG OF BORING

BORING NO. BV-1
SHEET 2 OF 2

CLIENT	PROJECT	PROJECT NO.
MidAmerican Energy Holdings Co.	Greenbay Power Station	7652

PROJECT LOCATION	COORDINATES	ELEVATION (DATUM)	TOTAL DEPTH	DATE STARTED
				09-10-99

SURFACE CONDITIONS	DATE FINISHED
	09-12-99

DRILLING CONTRACTOR	DRILL RIG

DRILLER	LOGGED BY
	DDMARLOW

SAMPLING: SAMP. TYPE | SAMPLE NUMBER | SET 6 INCHES | 2ND 6 INCHES | 3RD 6 INCHES | N VALUE | SAMPLE RECOVERY

CORE SIZE	RUN NUMBER	RUN LENGTH	RUN RECOVERY	RQD RECOVERY	PERCENT RECOVERY	RQD	DEPTH IN FEET	SAMPLE TYPE	LITHOLOGY LOG	CLASSIFICATION OF MATERIALS	REMARKS
			30.0								09-11-99
7½	3	5.0	5.0	4.5	100	90	2			As Above	100% Returns
							3				Rig break-down @ 35.0'
			35.0				5				09-12-99
½	4	5.0	4.0	4.0	80	80	7				
			40.0				40		NR	No Recovery 39.0-40.0'	
							41–45				End of Boring at 40.0 feet, Boring backfilled w/grout upon completion. No Water level recorded.
							50				
							55				

Bag or Grab Sample	California	Piston	Pitcher	Split Barrel	Thin Wall
⊠					

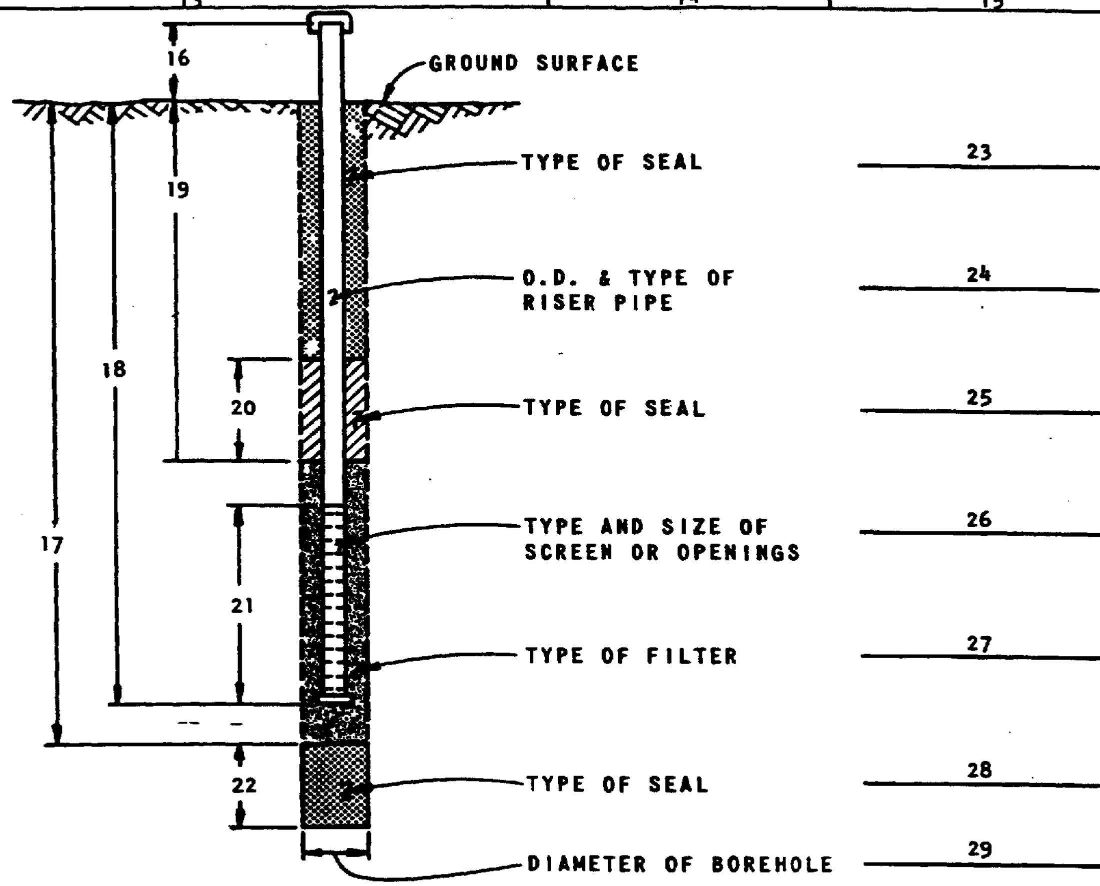
PIEZOMETER INSTALLATION LOG

BLACK & VEATCH
CONSULTING ENGINEERS

PIEZOMETER INSTALLATION LOG

PIEZOMETER NO. 4

CLIENT 1		PROJECT 2	PROJECT NO. 3
PROJECT LOCATION 5	COORDINATES 6	GROUND ELEVATION 7	DATE 8
STRATUM MONITORED 9		INSPECTOR 10	
CHECKED BY 11		APPROVED BY 12	
DRILLING CONTRACTOR 13		DRILL RIG 14	DRILLER 15



METHOD OF INSTALLATION: 30

REMARKS: 31

P-ST-0228

BLACK & VEATCH Corporation

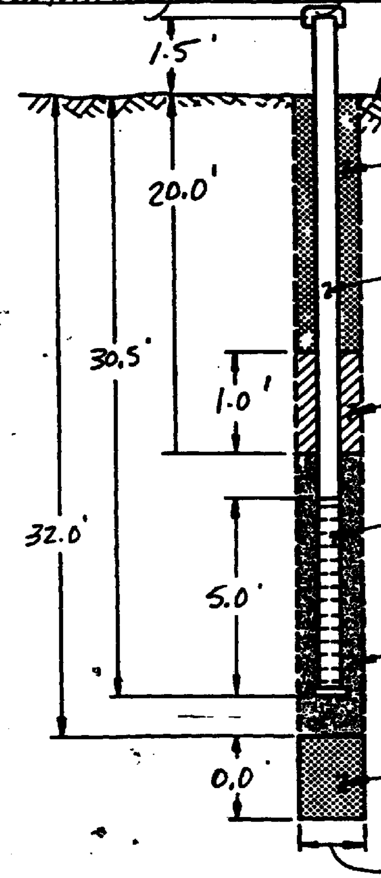
EXAMPLE PIEZOMETER INSTALLATION LOG

BLACK & VEATCH
CONSULTING ENGINEERS

PIEZOMETER INSTALLATION LOG

PIEZOMETER NO. P-12

CLIENT: City of Arvada		PROJECT: Blunn Reservoir	PROJECT NO. 9595
PROJECT LOCATION: Arvada, Colorado	COORDINATES: Sta. 9+80	GROUND ELEVATION: 5732.8	DATE: 3-6-84
STRATUM MONITORED: Weathered Claystone		INSPECTOR: M. Marasa	3-6-84
CHECKED BY: E. Meyer	4-11-84	APPROVED BY: R. Herzog	4-16-84
DRILLING CONTRACTOR: Custom Auger Drilling Service, Co.		DRILL RIG: CME-55	DRILLER: E. Parks



TYPE OF SEAL: Sand-Cement Grout

O.D. & TYPE OF RISER PIPE: 2" PVC

TYPE OF SEAL: Bentonite Pellets

TYPE AND SIZE OF SCREEN OR OPENINGS: 0.01" Slots

TYPE OF FILTER: Pea Gravel

TYPE OF SEAL: NA

DIAMETER OF BOREHOLE: 8"

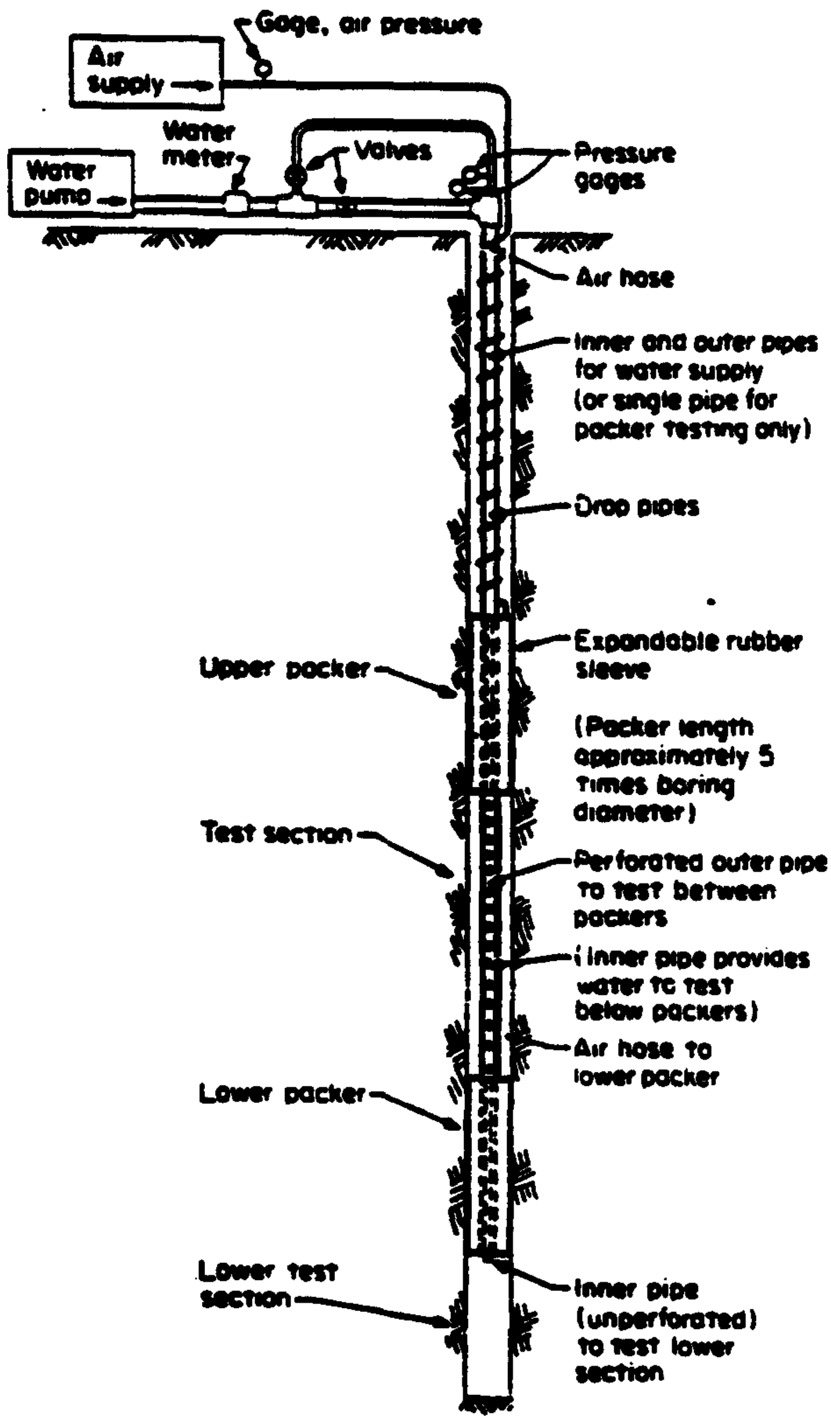
METHOD OF INSTALLATION: Boring drilled to completion; set riser pipe and screen; placed filter and seal; grouted to ground surface.

REMARKS: Piezometer developed by flushing with clear water until discharge was clear (45 minutes).

P-ST-0228

BLACK & VEATCH
Corporation

PRESSURE TESTING SETUP



APPENDIX B

DRILLING CONSULTANT SCOPE OF WORK WITH BLACK & VEATCH

APPENDIX C

ASTM D 2488 - 06 STANDARD PRACTICE FOR DESCRIPTION AND IDENTIFICATION OF SOILS (VISUAL-MANUAL PROCEDURE)

AND

ASTM D 2487 - 06 STANDARD PRACTICE FOR CLASSIFICATION OF SOILS FOR ENGINEERING PURPOSES (UNIFIED SOIL CLASSIFICATION SYSTEM)

APPENDIX D

ASTM D 2113 - 06 STANDARD PRACTICE FOR ROCK CORE DRILLING AND SAMPLING OF ROCK FOR SITE INVESTIGATION

APPENDIX E

ASTM D 5079 - 02 STANDARD PRACTICES FOR PRESERVING AND TRANSPORTING ROCK CORE SAMPLES

APPENDIX F

ASTM D 6032 - 02 STANDARD TEST METHOD FOR DETERMINING ROCK QUALITY DESIGNATION (RQD) OF ROCK CORE

APPENDIX G

PACKER PRESSURE TESTING FORMS

PACKER PRESSURE TESTING

Sheet ____ of ____

Boring No. ________ Test No. __________________ Test Interval: ________________

Step No(s). ____

Surface Gage units________	Transducer		Time from Start (min)	Flow Meter Reading units________	Time between Reading (min)	Δ Flow Meter units________	Flow Rate (per min)
	Pressure units________	Reading					
Step No.							
Step No.							
Step No.							

PACKER PRESSURE TESTING

Sheet _____ of _____

Boring No. __________ Test No. ____________________ Test Interval: ____________________

Step No(s). ____

Surface Gage units________	Transducer Pressure units________	Transducer Reading	Time from Start (min)	Flow Meter Reading units________	Time between Reading (min)	Δ Flow Meter units________	Flow Rate (per min)
Step No.							
Step No.							

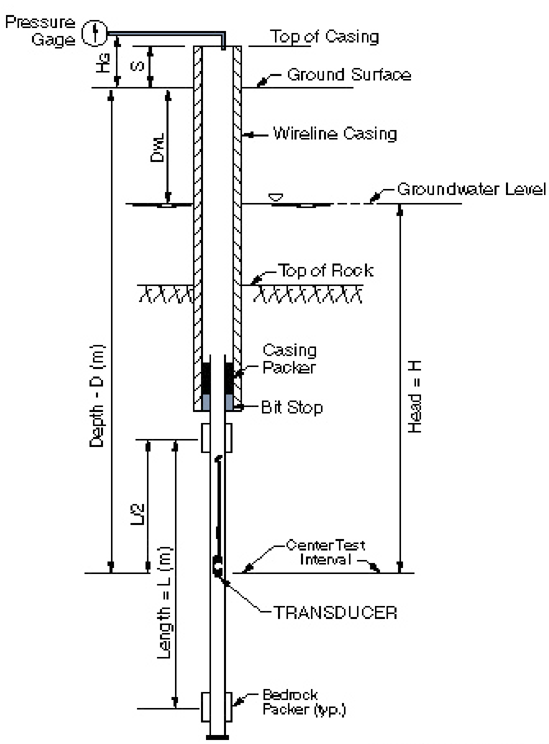
PRESSURE

PACKER PRESSURE TESTING

Sheet _____ of _____

Boring No. ______________________________	Transducer Serial No. ________________
Groundwater Level (DWL) ________________(m)	Calibration Factor (C)____________________
Test Interval ___________________________(m)	Zero Reading (R_0) _____________________
Depth (D)_____________________________(m)	Date of Test _________________________
PBL ___________________________________	Rig Supervisor ________________________

DEFINITIONS



PACKER PRESSURE TESTING

(Adapted for use with pressure transducer) in Metric Units

TEST PRESSURE

- **Baseline Pressure:** = PBL

  PBL = 22.6 kPa/m x D = ______ kPa

- **Transducer Pressure:** PTX

  PTX = (F) x PBL where (F) ranges from 0.5 to 1.0

  Transducer Reading: R_1

  PTX = C (R_0 - R_1) where: R_0 = Zero Reading

  R_1 = Required Reading

  C = Calibration Factor

  $R_1 = R_0 - \frac{P_{TX}}{C}$ Range = $R_1 \pm \frac{0.1\,P_{TX}}{C}$

- **Gage Pressure:** PGX

  PGX = PTX - 9.79 [D + HG]

- **Test Pressure:** PX

  PX = PTX - 9.79 [H] where: H = D-DWL

PRESSURE CALCULATIONS - STEPS

Step No.	Pressure Factor (F)	Pressure (PTX)	PTX/C	Transducer Reading R_1	Transducer Range +0.1 PTX/C	Transducer Range -0.1 PTX/C	Gage Pressure (PGX)	Head (H)	Test Pressure (PX)

PACKER PRESSURE TESTING

Sheet ____ of ____

Boring No. ______________________________ Transducer Serial No. __________________

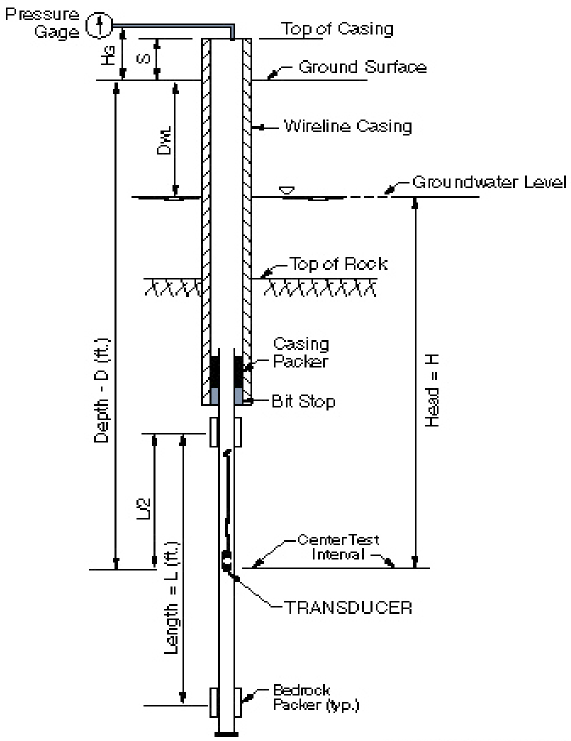
Groundwater Level (D_{WL}) ________________(Ft.) Calibration Factor (C)____________________

Test Interval _________________________(Ft.) Zero Reading (R_0) _____________________

Depth (D) ___________________________(Ft.) Date of Test _________________________

P_{BL} __________________________________ Rig Supervisor ________________________

DEFINITIONS



PACKER PRESSURE TESTING

(Adapted for use with pressure transducer) in English Units

TEST PRESSURE

- **Baseline Pressure:** = P_{BL}

  P_{BL} = 1.0 psi/ft x D = ______ psi

- **Transducer Pressure:** P_{TX}

  P_{TX} = (F) x P_{BL} where (F) ranges from 0.5 to 1.0

  Transducer Reading: R_1

  $P_{TX} = C\,(R_0 - R_1)$ where: R_0 = Zero Reading

  R_1 = Required Reading

  C = Calibration Factor

  $R_1 = R_0 - \frac{P_{TX}}{C}$ Range = $R_1 \pm \frac{0.1\,P_{TX}}{C}$

- **Gage Pressure:** P_{GX}

  $P_{GX} = P_{TX} - 0.433\,[D + H_G]$

- **Test Pressure:** P_X

  $P_X = P_{TX} - 0.433\,[H]$ where: $H = D - D_{WL}$

PRESSURE CALCULATIONS - STEPS

Step No.	Pressure Factor (F)	Pressure (P_{TX})	P_{TX}/C	Transducer Reading R_1	Transducer Range +0.1 P_{TX}/C	Transducer Range -0.1 P_{TX}/C	Gage Pressure (P_{GX})	Head (H)	Test Pressure (P_X)